US009471070B2

(12) **United States Patent**
Sabripour

(10) **Patent No.: US 9,471,070 B2**
(45) **Date of Patent: Oct. 18, 2016**

(54) **ENVIRONMENTAL CONTROL SYSTEM INCLUDING DISTRIBUTED CONTROL ELEMENTS**

(71) Applicant: **Shey Sabripour**, Austin, TX (US)

(72) Inventor: **Shey Sabripour**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/499,051**

(22) Filed: **Sep. 26, 2014**

(65) **Prior Publication Data**

US 2015/0019024 A1 Jan. 15, 2015

Related U.S. Application Data

(63) Continuation-in-part of application No. 13/345,698, filed on Jan. 7, 2012, now abandoned.

(60) Provisional application No. 61/431,202, filed on Jan. 10, 2011.

(51) **Int. Cl.**

G05B 11/01	(2006.01)
G05B 15/00	(2006.01)
G05D 23/19	(2006.01)
G06F 3/0484	(2013.01)
G06N 3/063	(2006.01)

(52) **U.S. Cl.**

CPC ***G05D 23/1927*** (2013.01); ***G05D 23/1917*** (2013.01); ***G06F 3/0484*** (2013.01); ***G06N 3/063*** (2013.01)

(58) **Field of Classification Search**

CPC . G05D 23/1927; H04W 4/005; H04L 67/12; G05B 2219/13144; G05B 2219/32128; G06F 3/048

USPC 700/17, 83

See application file for complete search history.

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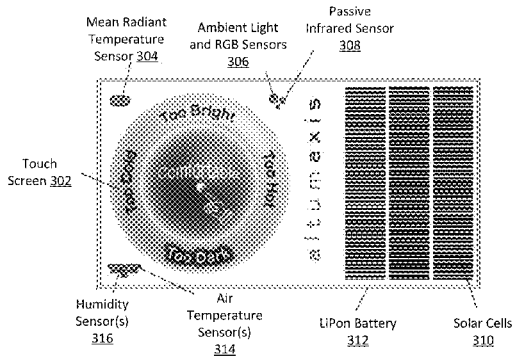
Primary Examiner — Ronald Hartman, Jr.

(74) *Attorney, Agent, or Firm* — Cesari & Reed LLP; R. Michael Reed

(57) **ABSTRACT**

An apparatus may include at least one sensor and a transmitter coupled to the at least one sensor and configured send data to a gateway through a wireless communication link. The apparatus may further include a solar cell configured to provide power to the at least one sensor and the transmitter. In some embodiments, the apparatus may include an adhesive backing configured to secure the apparatus to a structure.

20 Claims, 22 Drawing Sheets



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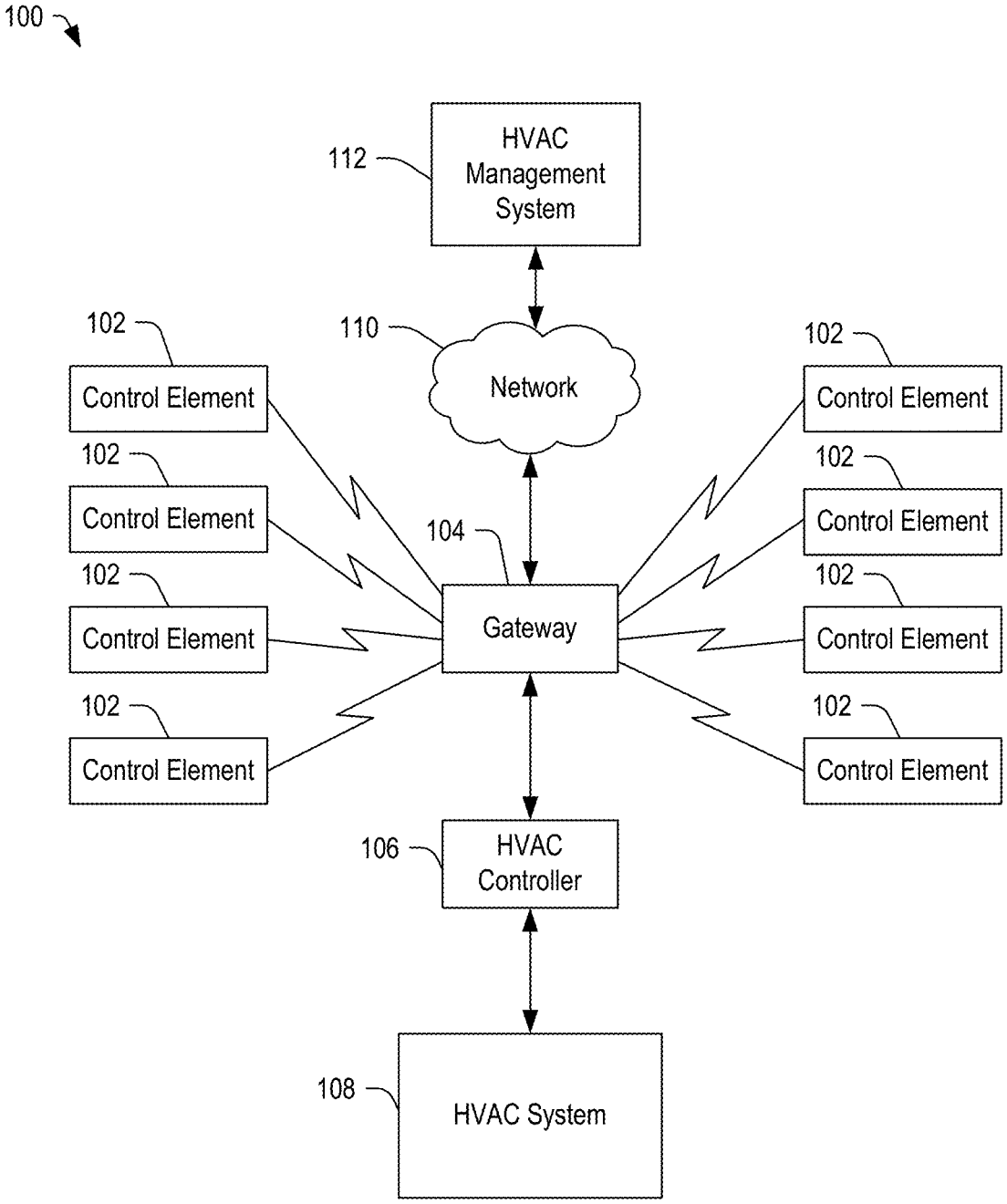
100
112
HVAC Management System
110
Network
102
Control Element
104
Gateway
106
HVAC Controller
108
HVAC System

FIG. 1

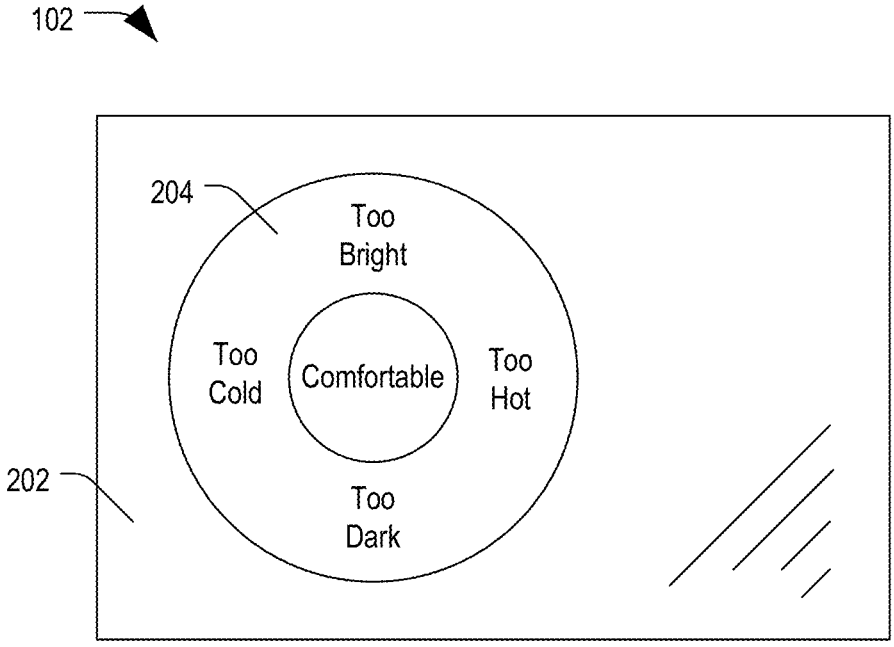
102
204
Too
Bright
Too
Cold
Comfortable
Too
Hot
Too
Dark
202

FIG. 2A

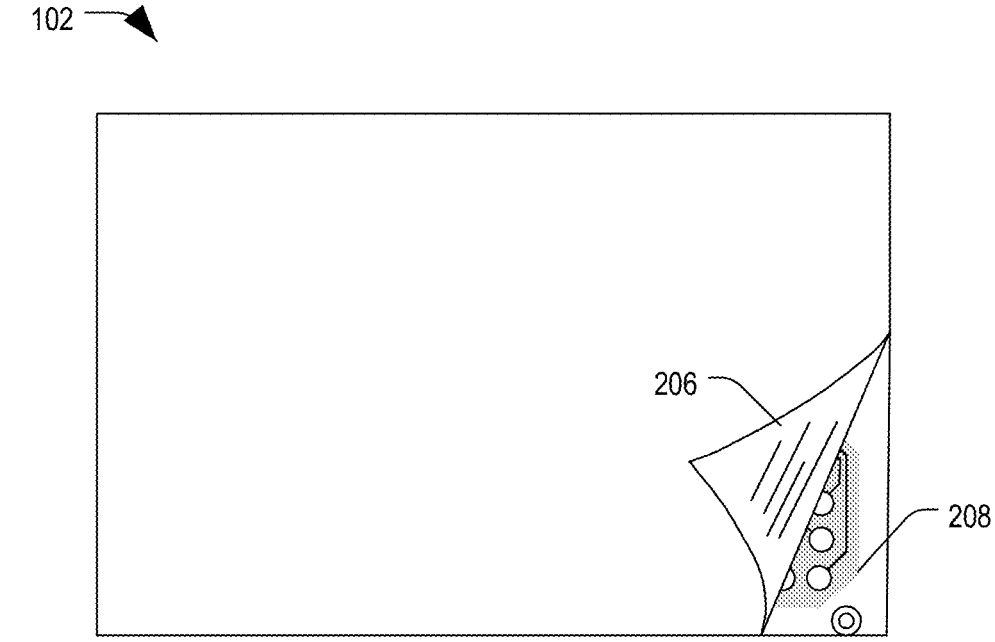
102
206
208

FIG. 2B

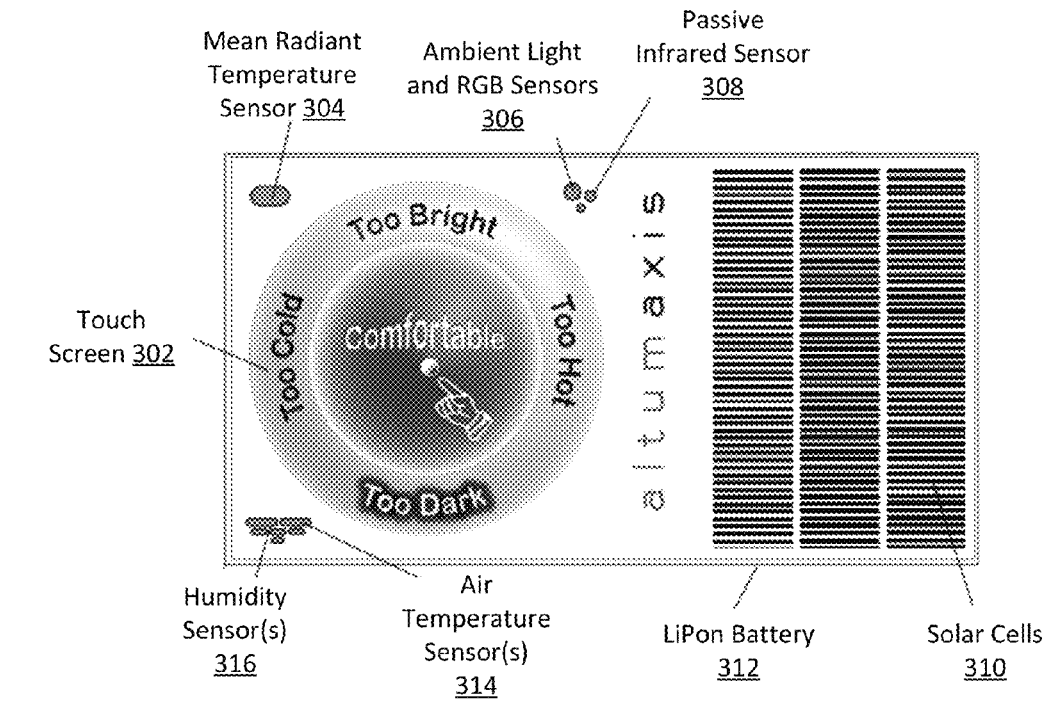
300
Mean Radiant Temperature Sensor 304
Ambient Light and RGB Sensors 306
Passive Infrared Sensor 308
Touch Screen 302
Too Bright
Too Cold
Comfortable
Too Hot
Too Dark
altumaxis
Humidity Sensor(s) 316
Air Temperature Sensor(s) 314
LiPon Battery 312
Solar Cells 310

FIG. 3

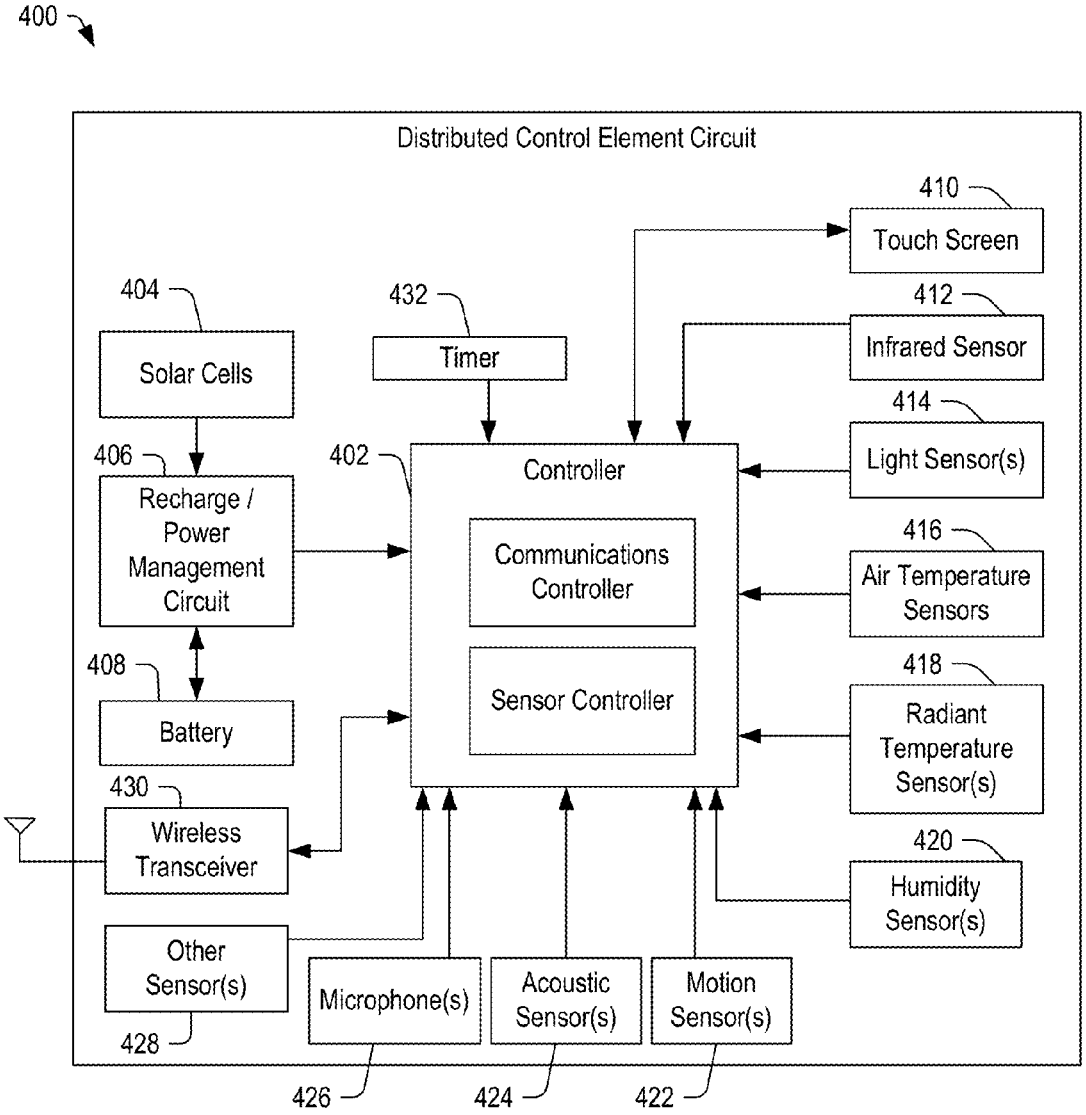
400
Distributed Control Element Circuit
410
Touch Screen
404
Solar Cells
432
Timer
412
Infrared Sensor
414
Light Sensor(s)
406
Recharge / Power Management Circuit
402
Controller
Communications Controller
Sensor Controller
416
Air Temperature Sensors
408
Battery
418
Radiant Temperature Sensor(s)
430
Wireless Transceiver
420
Humidity Sensor(s)
Other Sensor(s)
428
Microphone(s)
426
Acoustic Sensor(s)
424
Motion Sensor(s)
422

FIG. 4

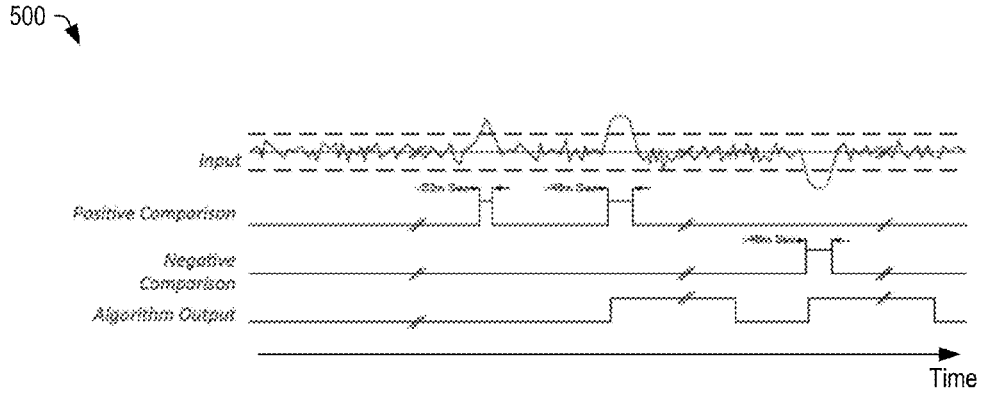

FIG. 5A

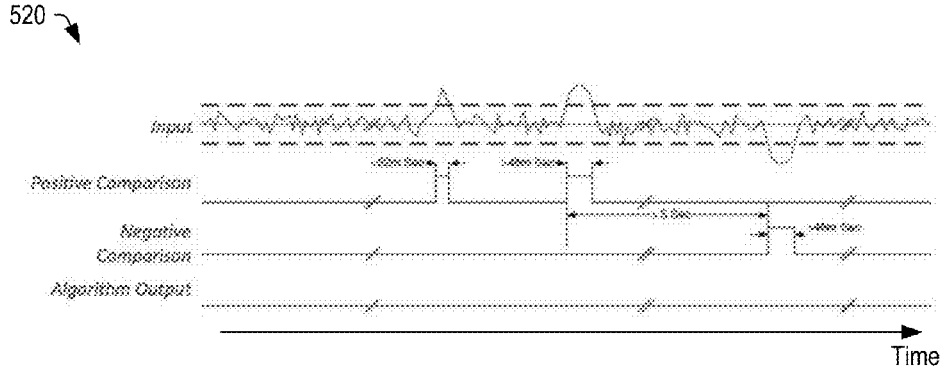

FIG. 5B

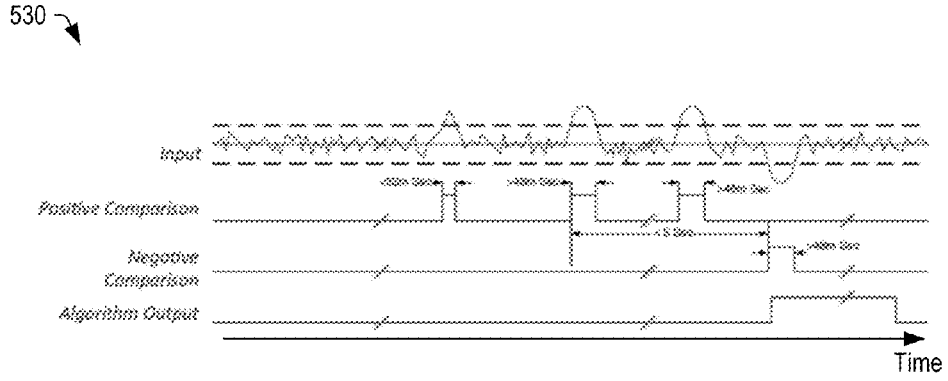

FIG. 5C

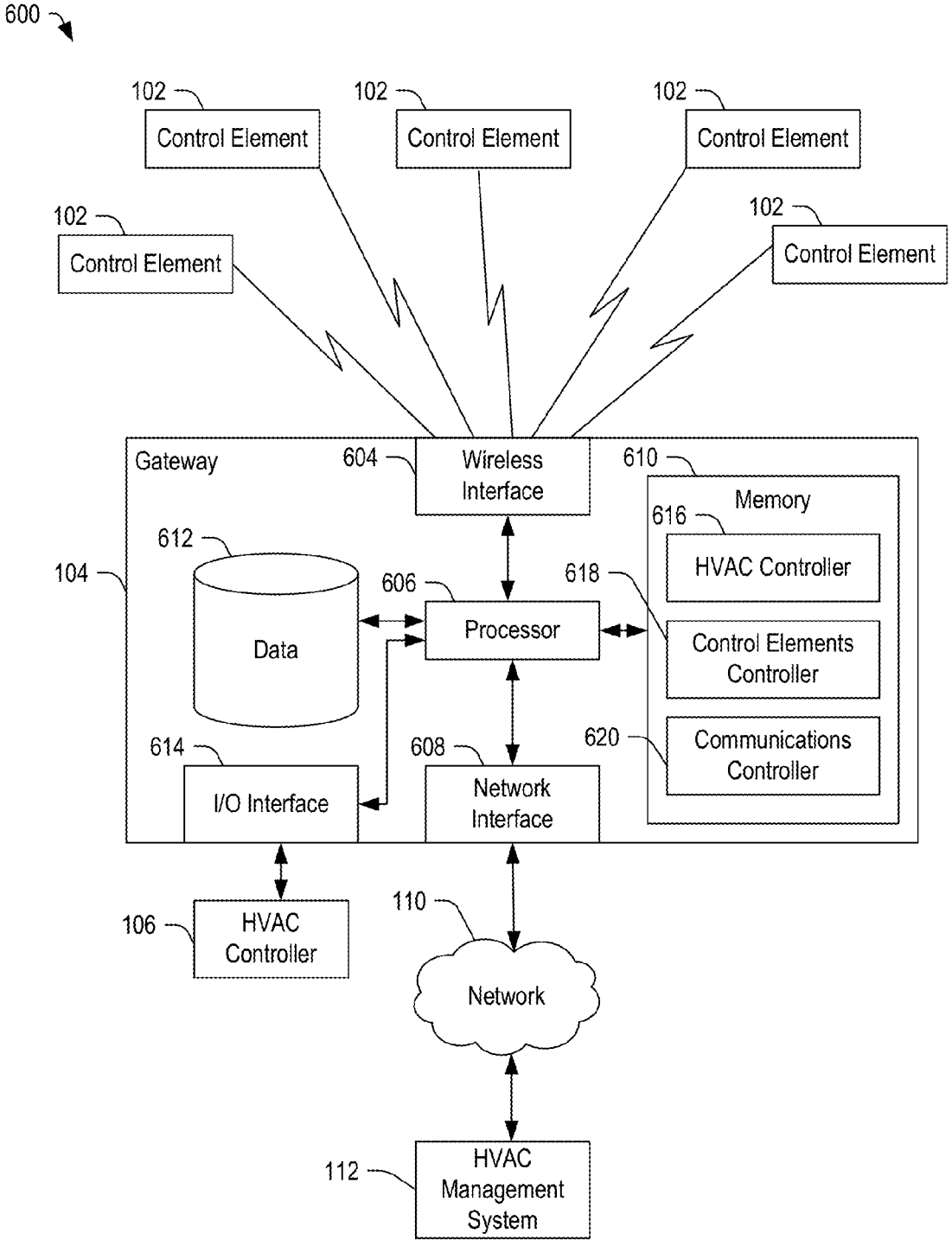
600
102
Control Element
102
Control Element
102
Control Element
102
Control Element
102
Control Element
Gateway
604
Wireless Interface
610
Memory
616
HVAC Controller
618
Control Elements Controller
620
Communications Controller
612
Data
104
606
Processor
614
I/O Interface
608
Network Interface
106
HVAC Controller
110
Network
112
HVAC Management System

FIG. 6

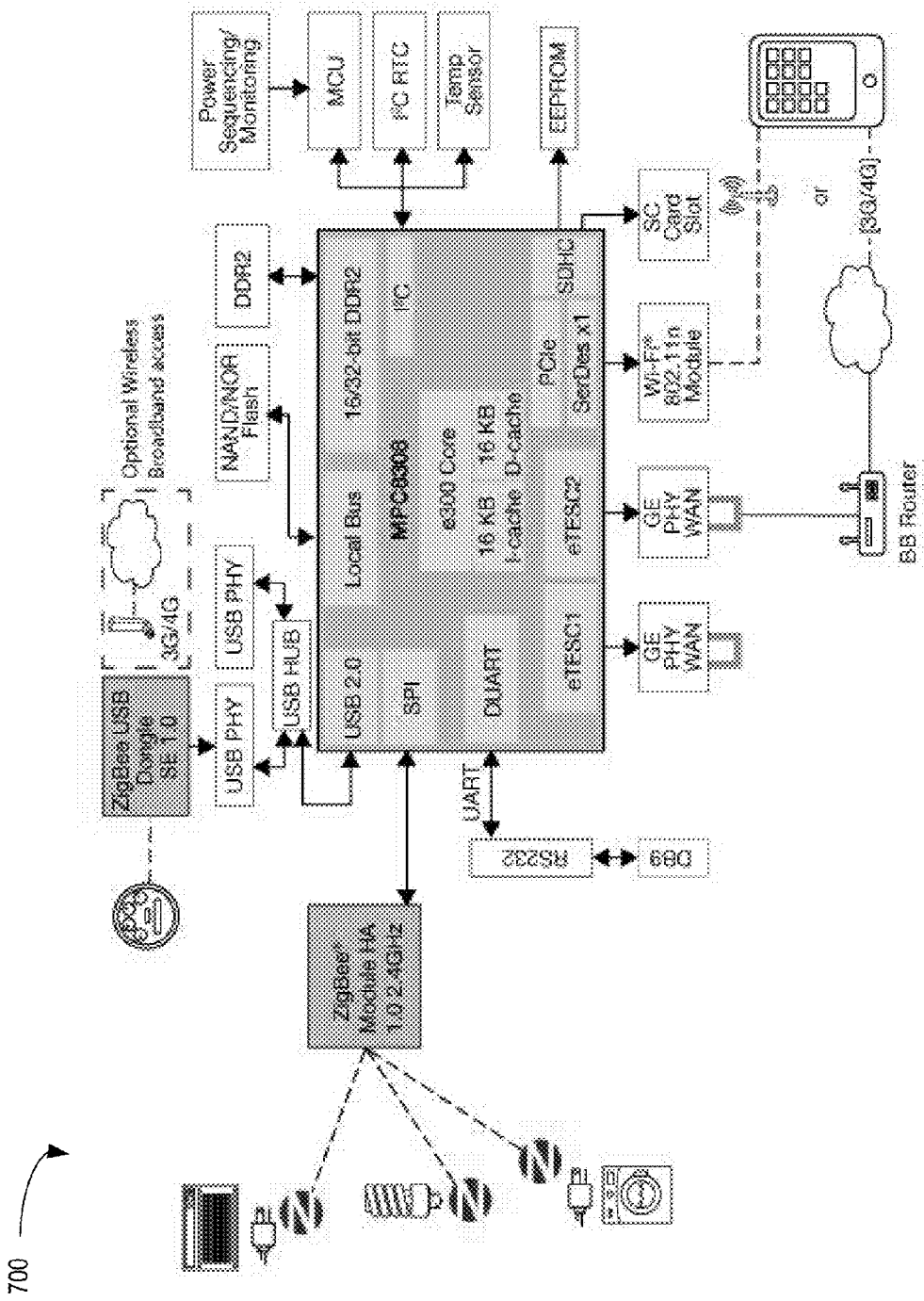
700
Power Sequencing/ Monitoring
MCU
I²C RTC
Temp Sensor
EEPROM
DDR2
NAND/NOR Flash
USB PHY
USB HUB
USB PHY
Optional Wireless Broadband access
3G/4G
ZigBee USB Dongle SE 1.0
Local Bus
16/32-bit DDR2
I²C
MPC8308
e300 Core
16 KB I-cache
16 KB D-cache
USB 2.0
SPI
DUART
eTESC1
eTESC2
PCIe SerDes x1
SDHC
SD Card Slot
Wi-Fi® 802.11n Module
GE PHY WAN
GE PHY WAN
UART
RS232
Db9
ZigBee® Module HA 1.0 2.4GHz
or
[3G/4G]
BB Router

FIG. 7

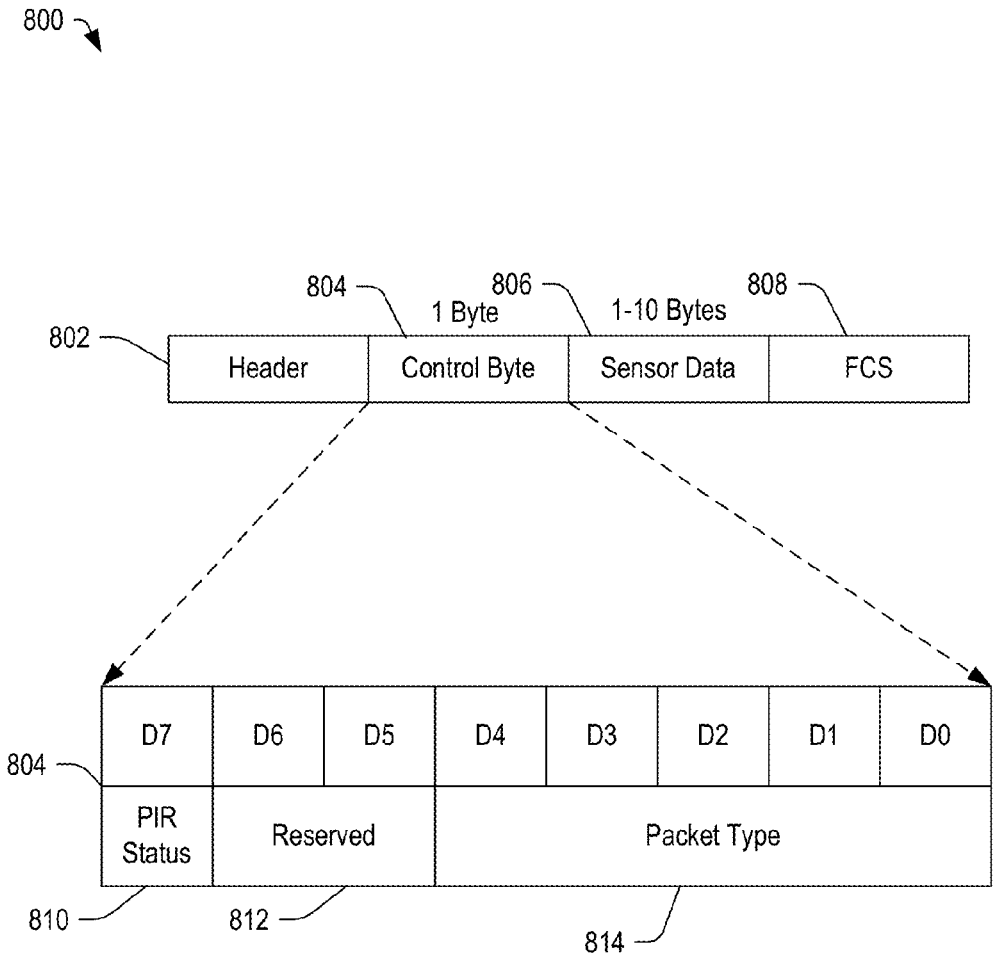
800
804
1 Byte
806
1-10 Bytes
808
802
Header
Control Byte
Sensor Data
FCS
D7
D6
D5
D4
D3
D2
D1
D0
804
PIR Status
Reserved
Packet Type
810
812
814

FIG. 8

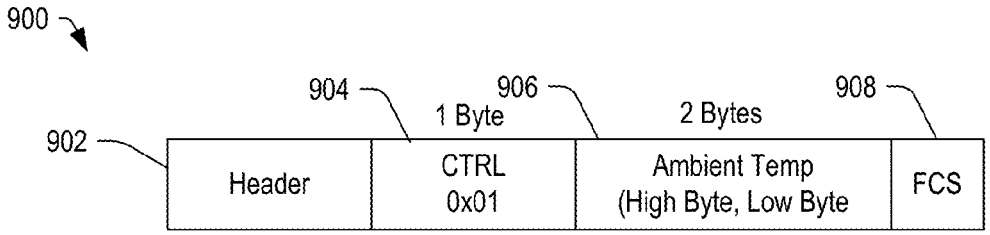

FIG. 9A

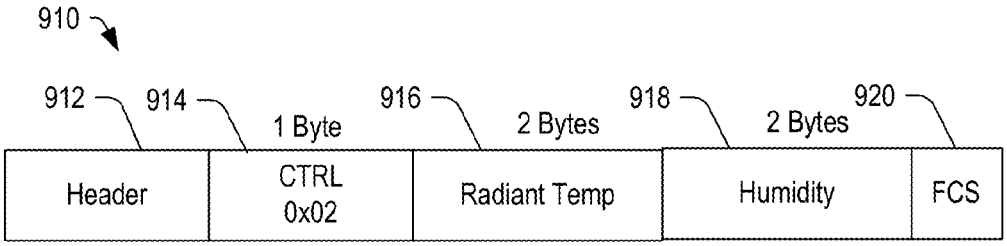

FIG. 9B

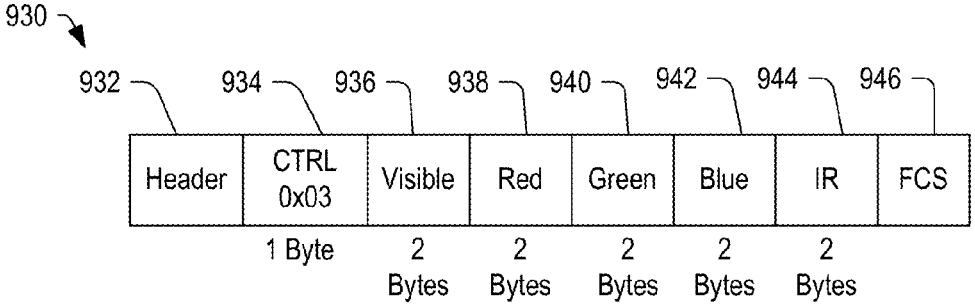

FIG. 9C

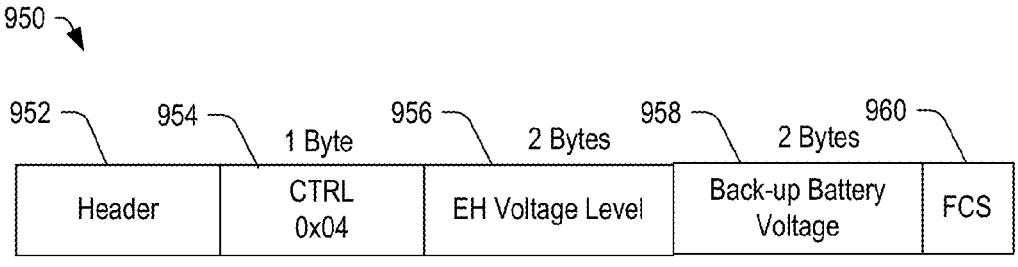

FIG. 9D

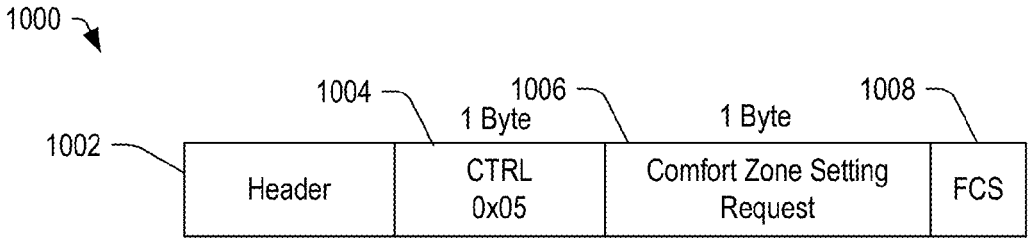

FIG. 10A

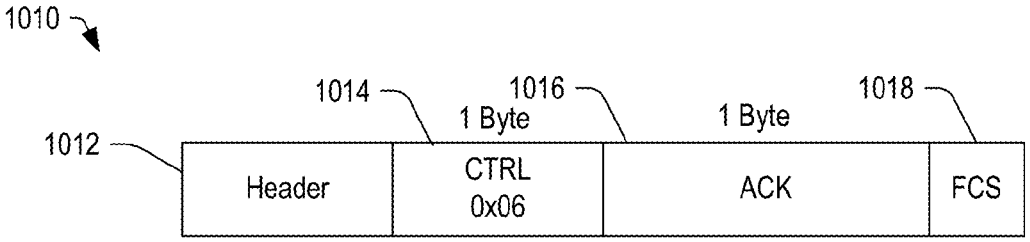

FIG. 10B

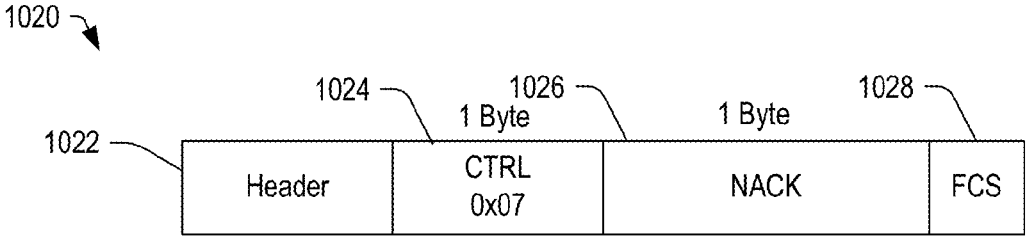

FIG. 10C

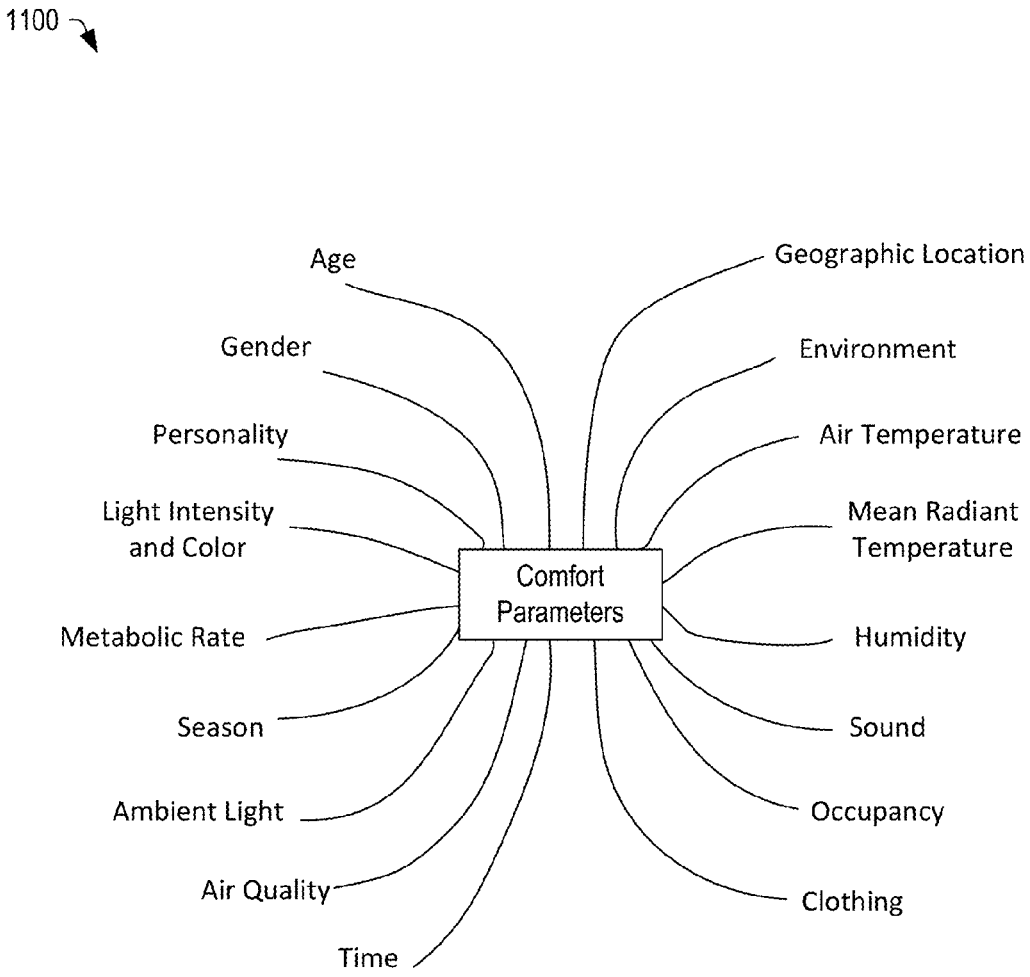
1100
Age
Gender
Personality
Light Intensity and Color
Metabolic Rate
Season
Ambient Light
Air Quality
Time
Geographic Location
Environment
Air Temperature
Mean Radiant Temperature
Humidity
Sound
Occupancy
Clothing
Comfort Parameters

FIG. 11

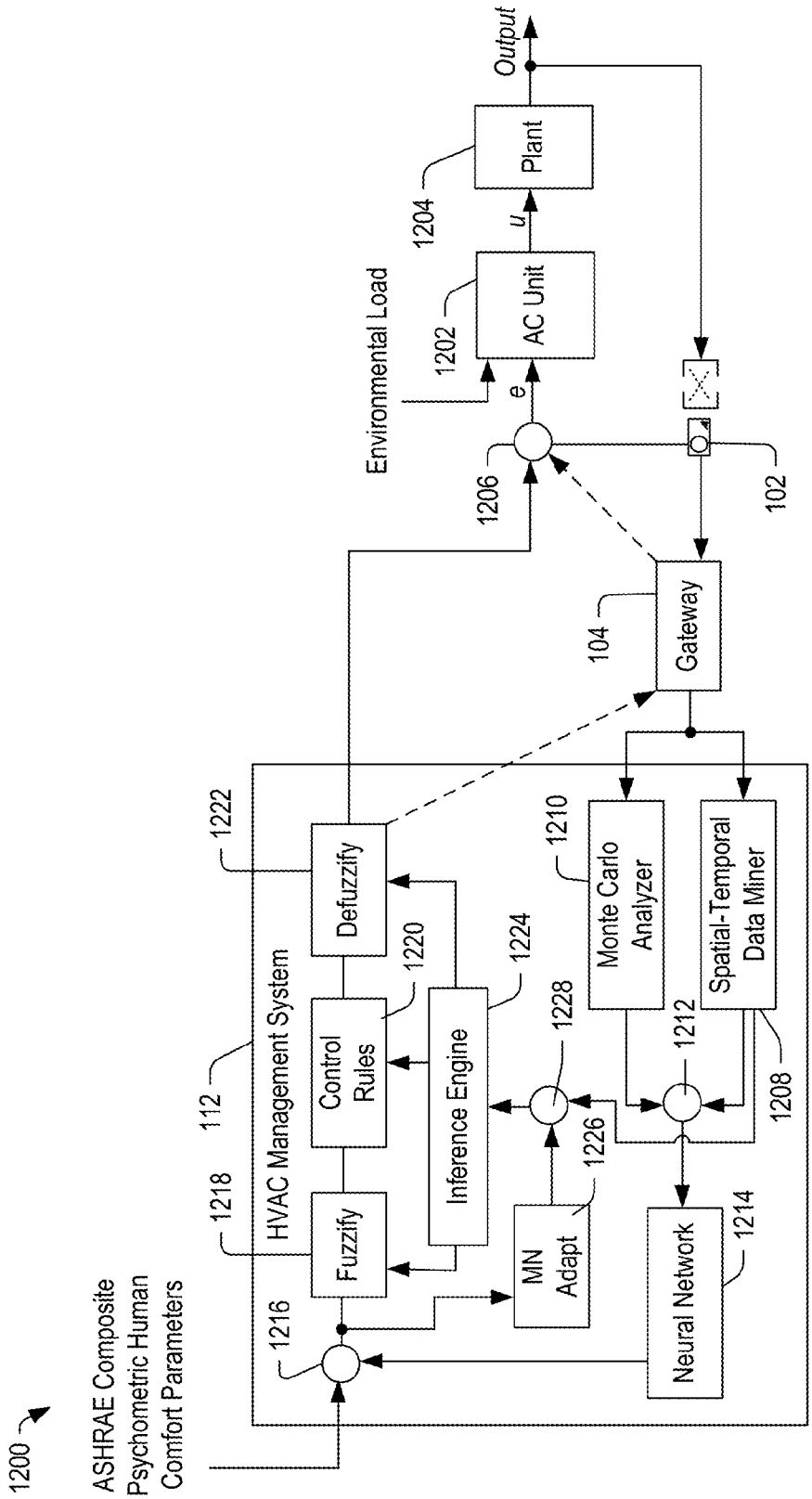
1200
ASHRAE Composite
Psychometric Human
Comfort Parameters
HVAC Management System
112
1218
Fuzzify
1216
Control
Rules
1220
Defuzzify
1222
Inference Engine
1224
MN
Adapt
1226
1228
Neural Network
1214
Monte Carlo
Analyzer
1210
Spatial-Temporal
Data Miner
1212
1208
Environmental Load
Feedforward
Gateway
104
102
1206
e
AC Unit
1202
u
Plant
1204
Environmental Load
Output

FIG. 12

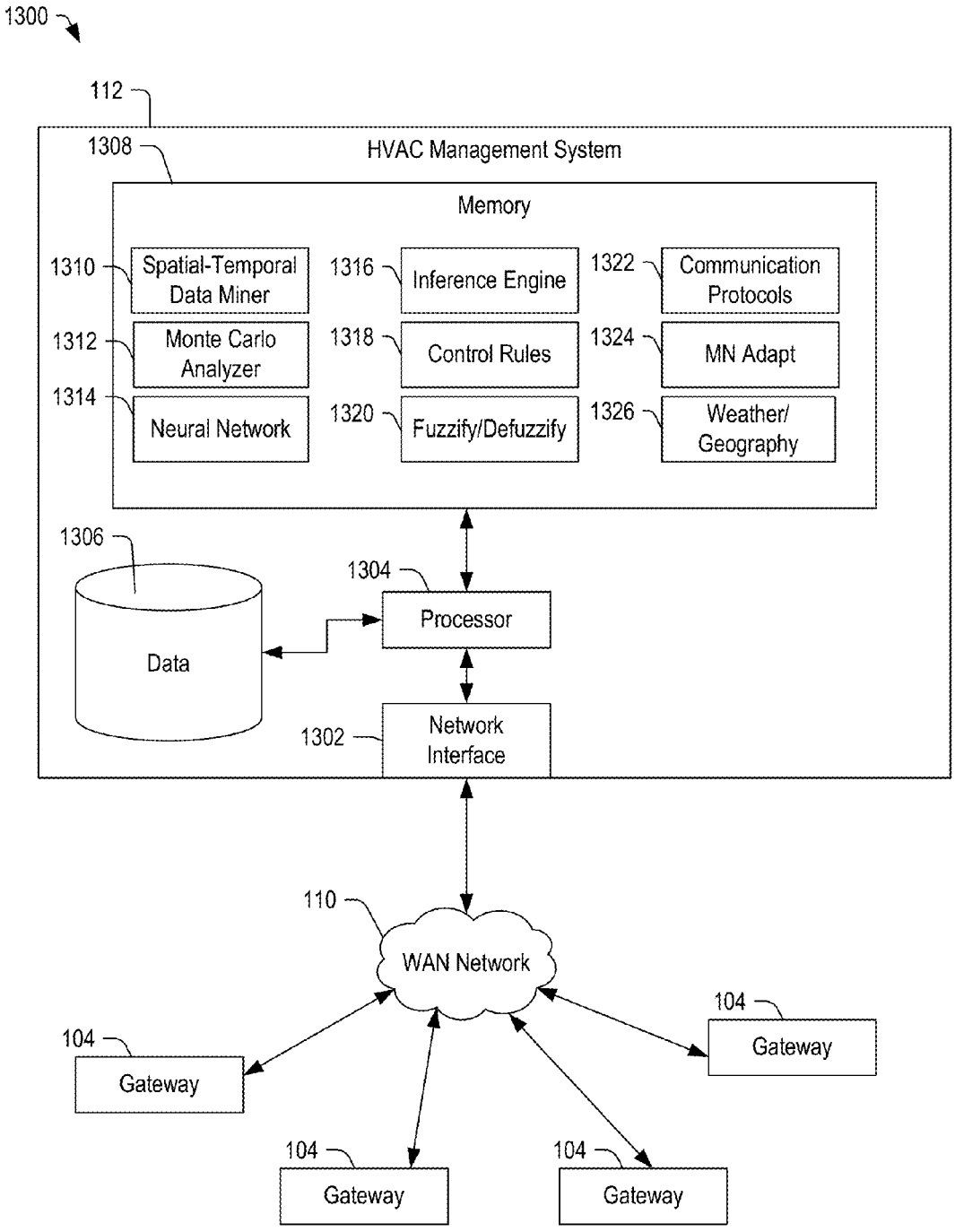
1300
112
1308
HVAC Management System
Memory
1310
Spatial-Temporal Data Miner
1316
Inference Engine
1322
Communication Protocols
1312
Monte Carlo Analyzer
1318
Control Rules
1324
MN Adapt
1314
Neural Network
1320
Fuzzify/Defuzzify
1326
Weather/ Geography
1306
Data
1304
Processor
1302
Network Interface
110
WAN Network
104
Gateway
104
Gateway
104
Gateway
104
Gateway
104
Gateway

FIG. 13

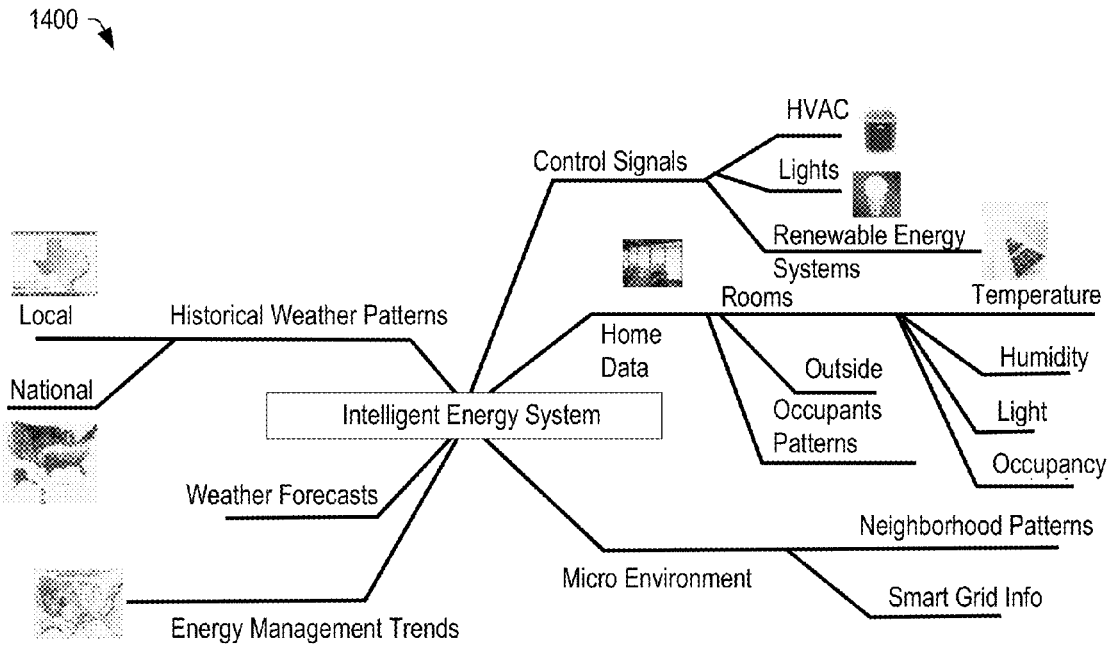
1400
HVAC
Control Signals
Lights
Renewable Energy Systems
Local
Historical Weather Patterns
Rooms
Temperature
Home Data
National
Outside
Humidity
Intelligent Energy System
Occupants Patterns
Light
Occupancy
Weather Forecasts
Neighborhood Patterns
Micro Environment
Smart Grid Info
Energy Management Trends

FIG. 14

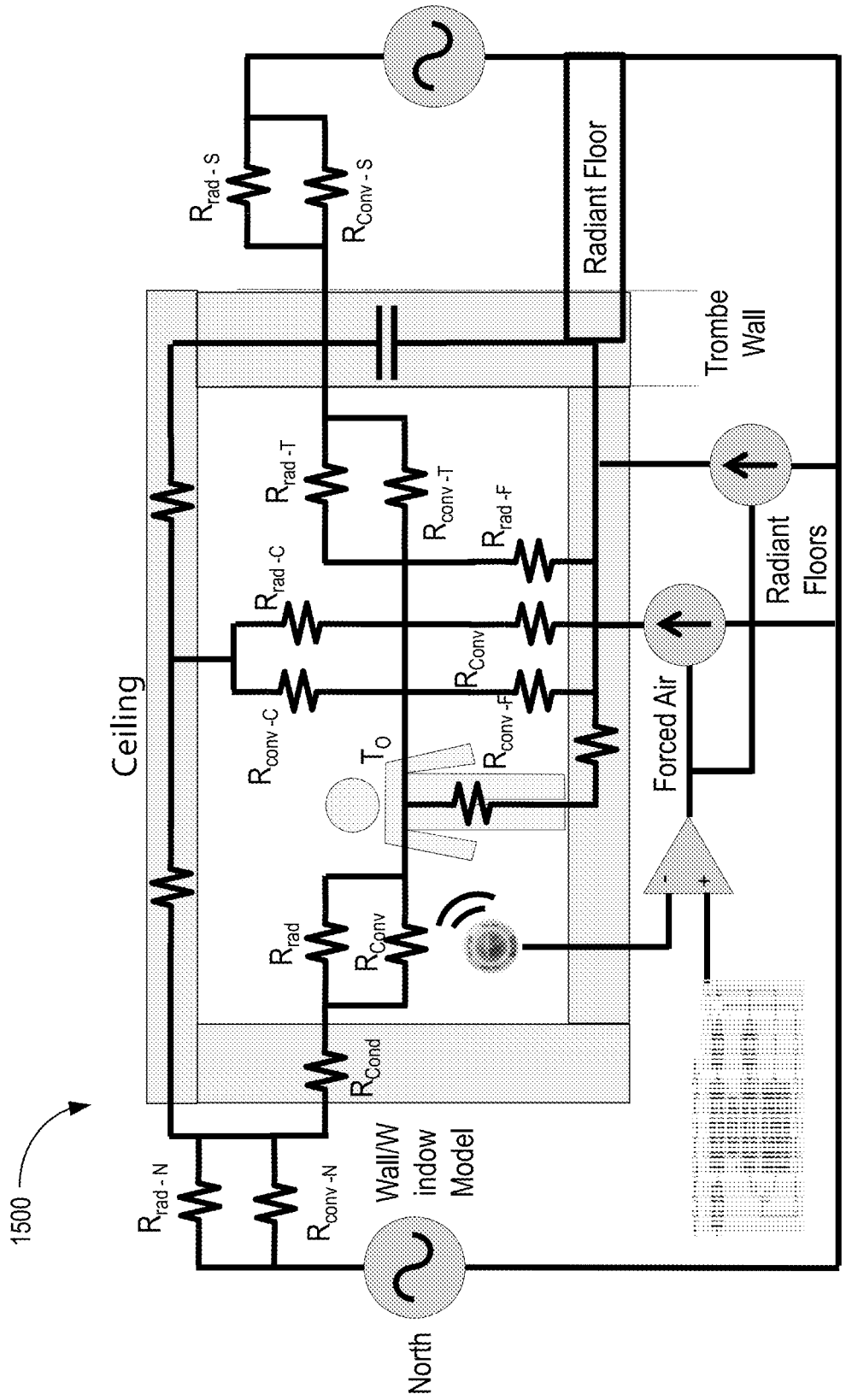
1500
Wall/Window Model
North
Ceiling
Trombe Wall
Radiant Floor
Radiant Floors
Forced Air
R_{rad-S}
R_{Conv-S}
R_{rad-T}
R_{conv-T}
R_{rad-F}
R_{rad-C}
R_{Conv}
R_{conv-C}
R_{conv-F}
T_O
R_{rad}
R_{Conv}
R_{Cond}
R_{rad-N}
R_{conv-N}

FIG. 15

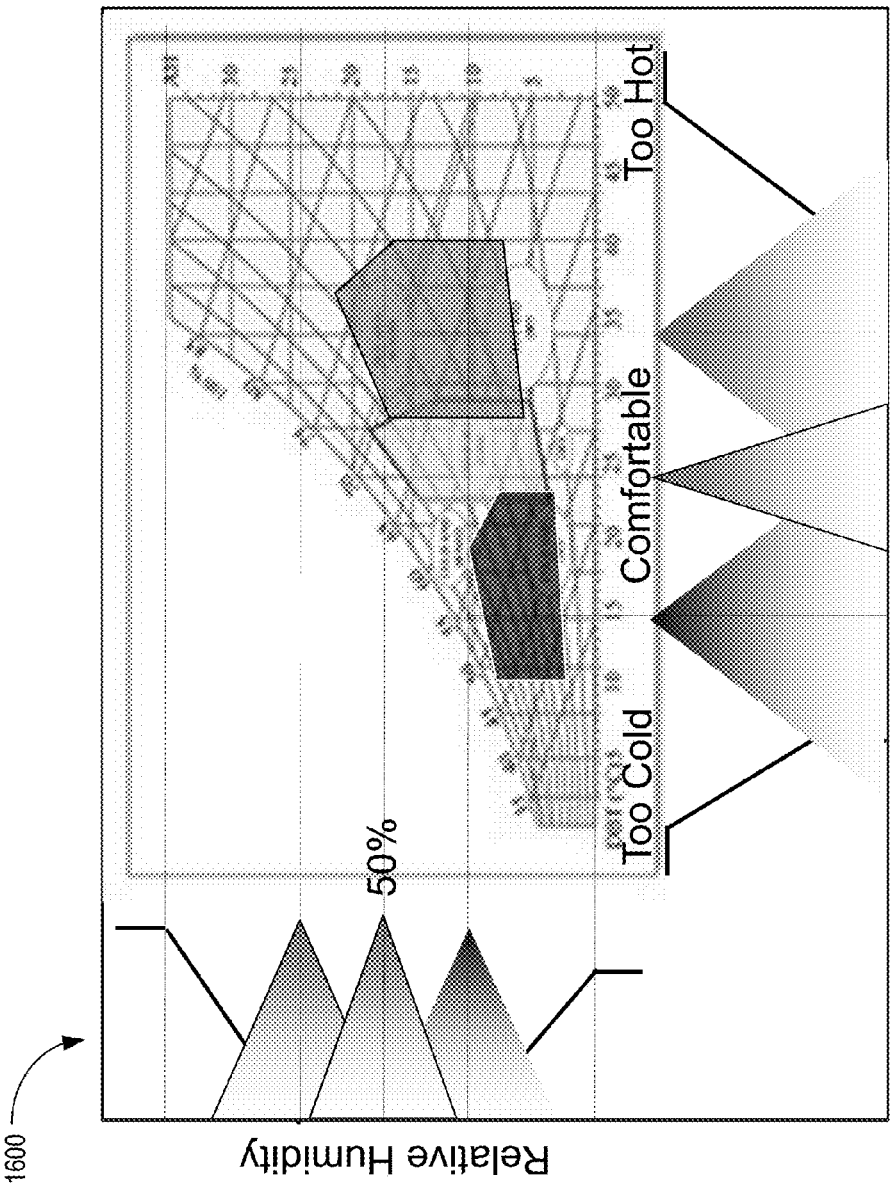
1600
Relative Humidity
50%
Too Cold
Comfortable
Too Hot
Mean Radiant Temperature

FIG. 16

(1) $\Delta U = Q - W$

(2) $\Delta U = TdS + pdV$

(3) $\eta = 1 - \frac{T_C}{T_H}$

(4) $Q_H - Q_C = W_{in}$

(5) $\Delta S = \frac{\Delta Q}{T}$

FIG. 17

1800

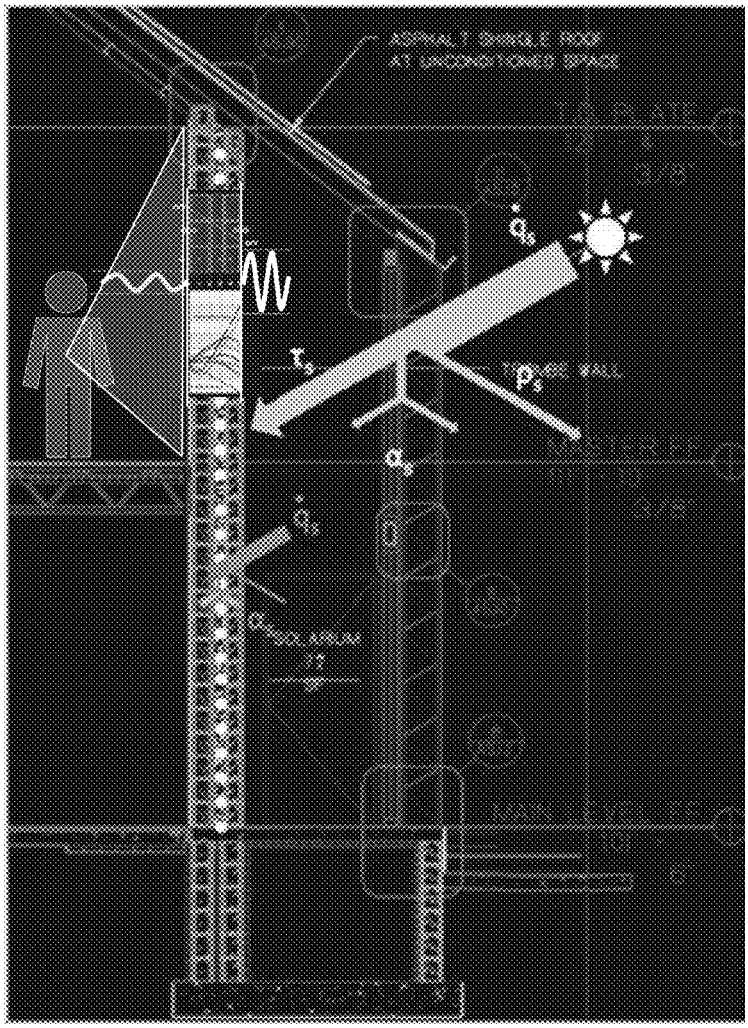

FIG. 18

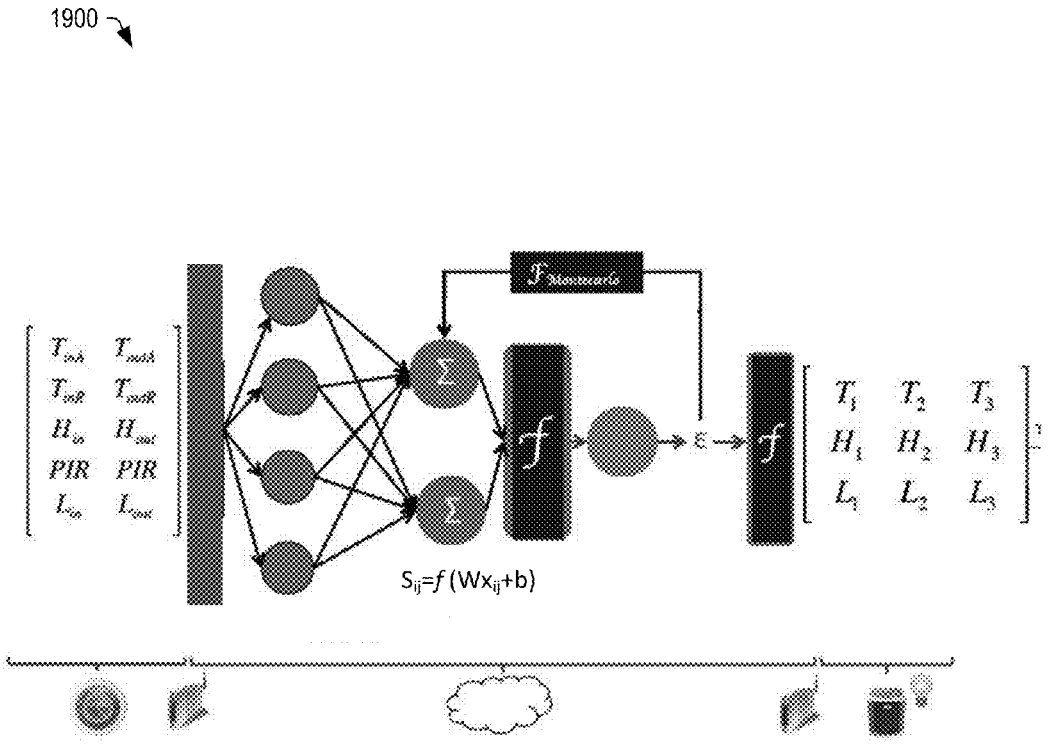

FIG. 19

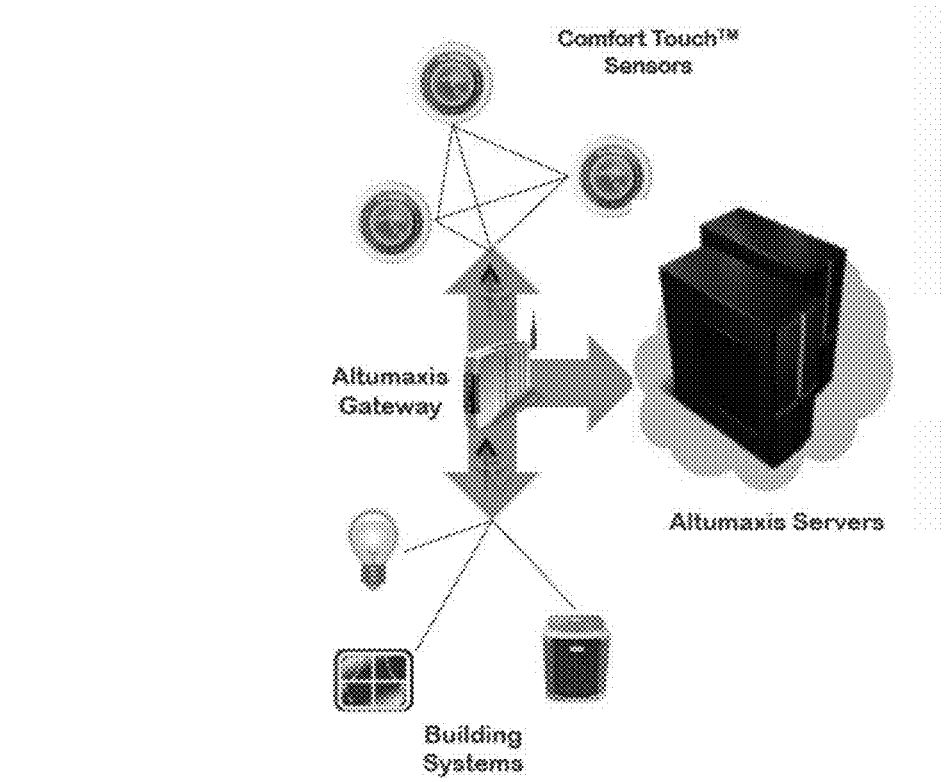
2000
Comfort Touch™
Sensors
Altumaxis
Gateway
Altumaxis Servers
Building
Systems

FIG. 20

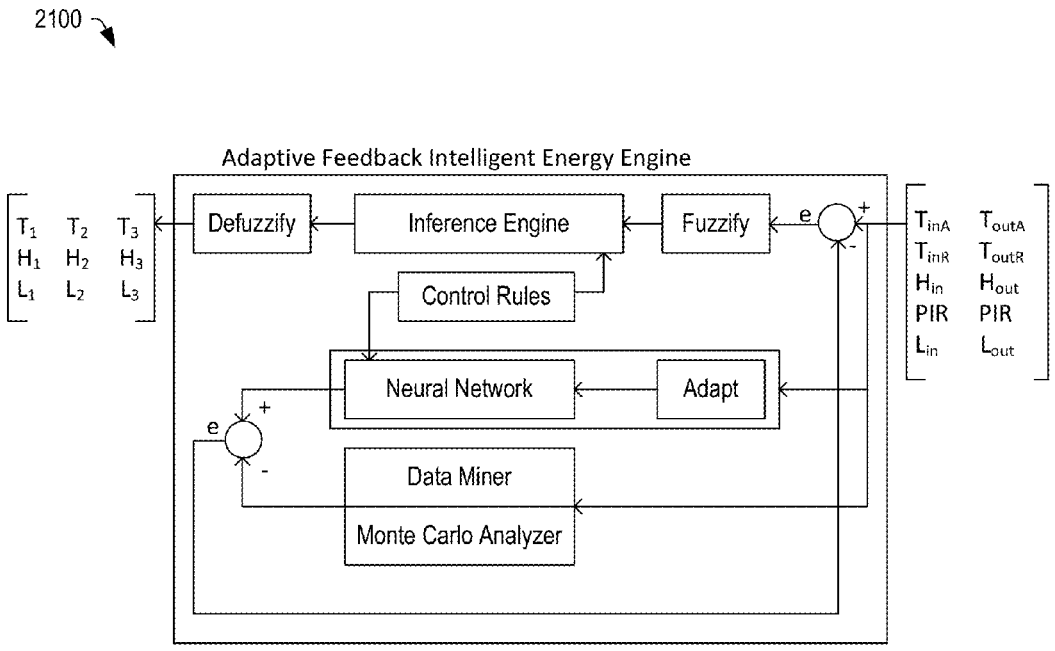
2100
Adaptive Feedback Intelligent Energy Engine
T1 T2 T3
H1 H2 H3
L1 L2 L3
Defuzzify
Inference Engine
Fuzzify
e
+
-
TinA ToutA
TinR ToutR
Hin Hout
PIR PIR
Lin Lout
Control Rules
Neural Network
Adapt
e
+
-
Data Miner
Monte Carlo Analyzer

FIG. 21

FIG. 22

ENVIRONMENTAL CONTROL SYSTEM INCLUDING DISTRIBUTED CONTROL ELEMENTS

CROSS-REFERENCE TO RELATED APPLICATION(S)

This application claims priority to and is a continuation-in-part of co-pending U.S. patent application Ser. No. 13/345,698 filed on Jan. 7, 2012 and entitled "Intelligent Energy System", which claimed priority to and was a non-provisional of provisional patent application No. 61/431,202 filed on Jan. 10, 2011 and entitled "Intelligent Energy System", both of which are incorporated herein by reference in their entireties.

FIELD

The present disclosure is generally related to environmental control systems, such as heating, ventilation, and air-conditioning (HVAC) systems, lighting systems, and other systems that consume energy, and more particularly, to environmental control systems that include distributed control elements.

BACKGROUND

In 2011, the Department of Energy indicated that buildings consume more than 40 quadrillion British Thermal Units (BTUs) per year, accounting for nearly 40 percent of energy use in the United States, for example. In contrast to the amount of energy consumed to achieve comfort levels in buildings, the actual energy needed to maintain human comfort (heating/cooling) and to satisfy other energy needs, such as entertainment, lighting, computing, cooking, domestic hot water, and the like, may be achieved using only a fraction of this amount. A large portion of the energy consumed is wasted through inefficient production and distribution.

HVAC systems in residential and commercial settings may utilize energy control elements that may manage environmental conditions in a limited environment, such as in the vicinity of the thermostat. However, such systems provide limited inputs to the HVAC control system (or may operate as the HVAC controller), resulting in limited system control. As a result, a poorly placed thermostat may result in wasted energy consumption and poor environmental management.

SUMMARY

In certain embodiments, an apparatus may include at least one sensor and a transmitter coupled to the at least one sensor and configured send data to a gateway through a wireless communication link. The apparatus may further include a solar cell configured to provide power to the at least one sensor and the transmitter.

In other certain embodiments, an environmental control system may include a plurality of control elements. At least some of the control elements may include a sensor and a transceiver coupled to the sensor. The transceiver may be configured to send data to a wireless communications link. At least some of the control elements may further include a solar cell configured to provide power to the at least one sensor and the transmitter. The environmental control system may include a gateway configured to receive data from the transceiver and to selectively control a heating, ventilation and air-conditioning (HVAC) system according to the data.

In still other certain embodiments, an apparatus may include a touch screen and a transmitter coupled to the touch screen and configured send data from the touch screen to a gateway through a wireless communication link. The apparatus may further include a solar cell configured to provide power to the touch screen and the transmitter.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an environmental control system including multiple distributed control elements, according to certain embodiments.

FIGS. **2**A and **2**B are diagrams of a distributed control element according to certain embodiments.

FIG. **3** is a diagram of a distributed control element according to certain embodiments.

FIG. **4** is a block diagram of a circuit of a distributed control element circuit according to certain embodiments.

FIGS. **5**A-**5**C are timing diagrams of a startup sequence, a calibration routine, and a pulse signature detection routine, according to certain embodiments.

FIG. **6** is a block diagram of an environmental control system including a gateway configured to communicate with distributed control elements according to certain embodiments.

FIG. **7** is a block diagram of a gateway for use with an environmental control system according to certain embodiments.

FIG. **8** is a block diagram of a packet format for data transmission between sensor nodes and a gateway of an environmental control system according to certain embodiments.

FIGS. **9**A-**9**D are packet formats for ambient temperature, radiant temperature, ambient light, and power levels respectively, according to certain embodiments.

FIGS. **10**A-**10**C are packet formats for comfort zone settings, acknowledgment, and negative acknowledgment respectively, according to certain embodiments.

FIG. **11** is a diagram depicting parameters affecting human comfort.

FIG. **12** is a block diagram of an environmental management system according to certain embodiments.

FIG. **13** is a block diagram of an environmental management system according to certain embodiments.

FIG. **14** is a block diagram of an environmental management system **1400** that provides multivariable adaptive control based on numerous comfort factors and external factors affecting the system.

FIG. **15** is a diagram of a multi-variable thermal analysis model of a plant according to certain embodiments.

FIG. **16** depicts a graph of relative humidity versus mean radiant temperature in a psychometric chart that correlates such parameters to perceived comfort according to certain embodiments.

FIG. **17** depicts a set of entropy equations according to certain embodiments.

FIG. **18** illustrates a representative example of environmental factors that may impact an environmental management system according to certain embodiments.

FIG. **19** is a diagram of a neural network-based intelligent energy engine according to certain embodiments.

FIG. **20** is a block diagram of an environmental management system according to certain embodiments.

FIG. **21** is a block diagram of an adaptive feedback intelligent energy engine according to certain embodiments.

FIG. **22** is a perspective view of a home, which may use the energy systems of FIGS. **1-22**, according to certain embodiments.

In the following discussion, the same reference numbers are used in the various embodiments to indicate the same or similar elements.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

In the following detailed description of embodiments, reference is made to the accompanying drawings which form a part hereof, and which are shown by way of illustrations. It is to be understood that features of various described embodiments may be combined, other embodiments may be utilized, and structural changes may be made without departing from the scope of the present disclosure. It is also to be understood that features of the various embodiments and examples herein can be combined, exchanged, or removed without departing from the scope of the present disclosure.

In accordance with various embodiments, the methods and functions described herein may be implemented as one or more software programs running on a computer processor or controller. In accordance with various embodiments, the methods and functions described herein may be implemented as one or more software programs running on a computing device, such as a tablet computer, smartphone, personal computer, server, or any other computing device. Dedicated hardware implementations including, but not limited to, application specific integrated circuits, programmable logic arrays, and other hardware devices can likewise be constructed to implement the methods and functions described herein. Further, the methods described herein may be implemented as a device, such as a computer readable storage medium or memory device, including instructions that when executed cause a processor to perform the methods.

Embodiments of environmental control systems are described below, which may include heating, air-conditioning and ventilation (HVAC) systems; lighting systems; and other systems that impact the environment of a space, such as an area within a building or structure. The systems may include one or more distributable control elements. The control elements may include a plurality of sensors, a touch-sensitive interface and a transceiver configured to communicate sensor data from the sensors and input data from the touch-sensitive interface to a control system through a wireless communication link. In certain embodiments, the control elements may include a battery and a solar cell, which may supply power to the sensors, the touch-sensitive interface and the transceiver. In certain embodiments, the control elements may be peel-and-stick devices, which may have an adhesive backing configured to attach the control element to a structure, such as a wall. The control elements may automatically communicate with a control system. In certain embodiments, the control elements may communicate with the control system through a gateway.

FIG. **1** is a block diagram of an environmental control system **100** including multiple distributed control elements **102**, according to certain embodiments. The control system **100** may include multiple control elements **102**, which may be distributed throughout a structure, such as a home, an office, a building, or any combination thereof. The environmental control system **100** may include a gateway **104**, which may communicate with each of the distributed control elements **102** through wireless communication links and which may communicate with an HVAC controller **106** of the structure. The gateway **104** may also communicate with an HVAC management system (intelligent energy engine) **112** through a network **110**, such as the Internet. The HVAC controller **106** may receive signals from the HVAC management system **112** via the gateway **104** and may communicate control signals to an HVAC system **108** in response to the signals from the HVAC management system **112**.

In certain embodiments, the gateway **104** may be installed in a structure and may be communicatively coupled to the HVAC controller **106**. In certain embodiments, the gateway **104** provides wireless connectivity between the distributed control elements **102**, the HVAC controller **106**, and the HVAC management system **112**.

The HVAC controller **106** may include one or more control circuits that control blowers, heaters, air conditioners, humidifiers, and other environmental systems within the structure. In certain embodiments, the gateway **104** may receive user input signals from the control elements and may selectively provide control signals corresponding to the user input signals to the HVAC controller **106** to control the HVAC system **108**. In certain embodiment, the gateway **104** may communicate the user input signals to the HVAC management system **112** (instead of or in addition to communicating the user input signals to the HVAC controller **106**. In certain embodiments, the HVAC management system **112** may process the user input signals against historical data and provide control signals to the gateway **104**, which may communicate the control signals to the HVAC controller **106** to adjust one or more environmental parameters (such as temperature, humidity, other parameters, or any combination thereof) of the HVAC system **108**. In certain embodiments, the HVAC controller **106** may be configured to control lighting, ceiling fans, and other electronic devices and systems and may be configured to impact a user's comfort level.

In certain embodiments, the gateway **104** may be installed in a structure and may be communicatively coupled to the HVAC controller **106** and to the network **110**. The multiple control elements **102** may be deployed throughout the structure. In certain embodiments, the multiple control elements **102** may operate without a wired connection, deriving power from solar energy and communicating sensor signals and user inputs to the gateway **104** through wireless communication links.

In certain embodiments, the HVAC management system **112** may be implemented as a cloud-based system for efficient data collection and maintenance. The HVAC management system **112** may provide a heuristics-based artificial intelligence (AI) dynamic control configured to bridge the gap between subjective human-comfort parameters and necessary numerical precision needed for optimum heat transfer controls of building systems.

In certain embodiments, the gateway **104** may accumulate specific environmental data from the surrounding building zones (i.e., from the distributed control elements **102**), microclimate information, and transmits data (optionally including user input) to the gateway **104**. The gateway **104** receives sensor data from the distributed control elements **102** and transfers the data to the HVAC management system **112**. The HVAC management system **112** may process the data according to ASHRAE's (formerly the American Society of Heating, Refrigerating and Air Conditioning Engineers) psychrometric human comfort parameters and according to one or more other parameters. The HVAC

management system **112** may provide control signals to the gateway **104** to adjust the HVAC system **108**, to adjust lighting, to control other parameters, or any combination thereof.

In some embodiments, the environmental control system **100** may operate in a network mode, a standalone mode, a manual mode, or another mode. In the network mode, the gateway **104** may be communicatively coupled to the network **110**, such as the Internet. The gateway **104** may send sensor and user data to the HVAC management system **112**, may receive control signals (in response to the sensor and user data) from the HVAC management system **112**, and may provide the control signals to the HVAC controller **106**.

In a standalone mode, the gateway **104** may not be coupled to the network **110**. In this mode, the gateway **104** may provide state-optimized control signals to the HVAC controller **106** in response to sensor data, user inputs, or a combination thereof.

In a manual override mode, the gateway **104** and the distributed control elements **102** may utilize a fixed proportional-Integral-Differential (PID) ROM-booted (read-only memory booted) control algorithm, which may be similar to operation of a traditional thermostat. This manual override mode may ensure that system control of the HVAC systems **108** can still be maintained under worst case conditions and in response to user request for manual/rapid control of the system **100**.

In some embodiments, the gateway **104**, the HVAC management system **112** and the distributed control elements **102** provide elements that can convert an existing HVAC system into a smart HVAC system, which may achieve user comfort with enhanced energy efficiency. Additionally, because each of the distributed control elements **102** may be communicatively coupled to the gateway **104** without the need for wiring for power or communication, the distributed control elements **102** may be positioned in a variety of locations throughout the plant (or structure), preferably in a position to receive sufficient light to power its solar cell.

FIGS. **2**A and **2**B are diagrams of a distributed control element **102** according to certain embodiments. FIG. **2**A depicts a front-view of the distributed control element **102**, while FIG. **2**B depicts a back-side view of the distributed control element **102** with a portion of a peel-away cover **206** partially peeled back.

The distributed control element **102** may include a touch-sensitive interface **202**, which may include a touch-control feature **204**, which may be accessed by a user to provide user input that may affect the HVAC system **108**. In certain embodiments, a portion of the distributed control element **102** may include the touch-sensitive interface and another portion of the distributed control element **102** may include a solar cell, which may provide power to the distributed control element.

In certain embodiments, the distributed control element **102** may be formed from a flexible or rigid circuit substrate, which may be mounted to a structure, such as a wall, using an adhesive backing. The distributed control element **102** may include a peel-and-stick adhesive backing that includes a peel-away cover **206**, which may be removed to expose an adhesive backing, which may be pressed against the structure to attach the distributed control element **102** to the structure. The distributed control element **102** may include circuitry **208**, which is partially depicted in FIG. **2**B.

In certain embodiments, the distributed control element **102** may include a solar cell to generate electricity from available light, a battery to store electrical charge from the solar cell, the touch-sensitive interface **202** including the touch control feature **204**. In the illustrated example, the touch control feature **204** may be a "wheel"-shaped control element representing a circular gradient between various comfort states: "Too Bright", "Too Dark", "Too Cold", "Too Hot", or "Comfortable" (i.e., just right). The distributed control element may also include a variety of sensors, such as temperature sensors, light sensors, humidity sensors, and so on.

In certain embodiments, a user may interact with the touch-sensitive interface to provide input corresponding to the user's general comfort level expressed in terms of light levels and temperature levels. In certain embodiments, the user input may be sent to the HVAC management system **112** together with data from various sensors associated with the distributed control element **102**. The HVAC management system **112** may process the received data and may send control signals to the HVAC controller **106** through the network **110** and the gateway **104** to make adjustments to various parameters (such as humidity, temperature, fan speed, other parameters, or any combination thereof) of the HVAC system **108**.

FIG. **3** is a diagram of a distributed control element **300** according to certain embodiments. The distributed control element **300** includes a touch screen **302** accessible by a user to adjust comfort settings of an HVAC system, such as the HVAC system **108**. The distributed control element **300** may further include a mean radiant temperature sensor **304**, ambient light and red/green/blue (RGB) sensors **306**, and a passive infrared sensor **308**. The distributed control element **300** may also include one or more solar cells **310**, a battery **312** (such as a lithium ion battery, a lithium phosphorous oxynitride (LiPon) battery, or another rechargeable type of battery), one or more air temperature sensors **314**, and one or more humidity sensors **316**.

In certain embodiments, the distributed control element **300** may be a wireless, energy harvesting, sensor node with a human user interface (touch screen **302**) that may be configured to communicate with an HVAC management system **112**, which may be a cloud-based control system designed to determine and maintain human comfort factors, instead of just managing the ambient air and the humidity parameters of the particular environment.

In certain embodiments, the distributed control element **300** may be one of a plurality of such control elements distributed throughout a particular plant, such as a home or business. The distributed control element **300** may be part of an environmental control system, such as the control system **100** (in FIG. **1**), and may communicate wirelessly with the gateway **104** to provide sensor data and user inputs to at least one of the HVAC controller **106** and the HVAC management system **112**.

In certain embodiments, the distributed control element **300** may provide a linguistic, touch-interface **302** that keeps humans in the loop, has low initial cost, and low operating costs. The distributed control element **300** may be wireless, and may harvest energy from ambient light in order to provide distributed control and measurement capability with low maintenance and without having to add wiring. By measuring light, temperature, humidity, etc., the distributed control element **300** may measure multiple parameters affecting human comfort—not just ambient temperature.

In some embodiments, the control element **300** serves as an input to the energy management system **112** and to the HVAC controller **106**. The control element **300** may be powered through an energy-harvesting power system that uses solar cells that charge a rechargeable battery **312**. In

some embodiments, the rechargeable battery **312** may include a 1 mA-hr LiPon battery as well as a single coin cell lithium battery for back-up power to the display. The control element **300** may include a graphical user interface (GUI) displayed on a touch-interface **302**. The sensors may measure various parameters for system input including averaged radiant temperature of the environment; ambient air temperature; sensor self-temperature; ambient light and RGB color; relative humidity; passive infrared occupancy senor; and occupant touch frequency and multipoint input data.

In some embodiments, the user interface is through the touch screen **302**, which may be capacitive. The control element **300** may enter an idle, low-power mode and may wake periodically to measure various parameters, to communicate the sensor data to the gateway **104**, and then to return to the idle, low-power mode. In some embodiments, the control element **300** may enter an operating state when the touch interface **302** is touched. Depending on where the user touches on the touch screen **302** or how the user moves the sliding scale, such as by touching and dragging across the touch screen **302**, the user can indicate his or her comfort level (i.e., if he or she is too hot, too cold, and whether the room is too bright, or too dark).

The data obtained with these measurements may be transmitted wirelessly to the gateway **104**. A block diagram of the control element is shown below. Included in the diagram are all of the sensors and the power system.

FIG. **4** is a block diagram of a circuit **400** of a distributed control element circuit according to certain embodiments. The circuit **400** may be part of the distributed control element **102** in FIGS. **1**, **2**A and **2**B or of the distributed control element **300** in FIG. **3**. The circuit **400** may include a controller **402**, which may be implemented as a microcontroller unit (MCU) and which may include a communication controller and a sensor controller. The circuit **400** may further include one or more solar cells **404**, which may be coupled to a recharge/power management circuit **406**. The recharge/power management circuit **406** may provide current from the one or more solar cells **404** to a battery **408** and may provide power to the controller **402** and to other components of the distributed control element circuit **400**.

The circuit **400** may include a touch screen **410** and associated circuitry coupled to the controller **402**. The circuit **400** may further include one or more infrared sensors **412**, one or more light sensors **414**, one or more air temperature sensors **416**, one or more radiant temperature sensors **418**, one or more humidity sensors **420**, one or more motion sensors **422**, one or more acoustic sensors **424**, one or more microphones **426**, other sensors **428**, or any combination thereof. Each of the sensors **414**, **416**, **418**, **420**, **422**, **424**, and **428** and the microphones **426** may be coupled to the controller **402**. The circuit **400** may also include a wireless transceiver **430** coupled to the controller **402**. The circuit **400** may also include a timer **432**.

In some embodiments, the motion sensor **422** may detect movement in an area proximate to the circuit **400**, which movement may be indicative of an occupant. The motion sensor **422** may detect movement and generate a signal to the MCU **402**, causing the MCU to wake up from a low power mode, such as a sleep or idle mode.

In certain embodiments, the controller **402** may enter a sleep or idle mode and may wake up in response to user interaction with the touch screen **410** or may wake up periodically (in response to a signal from the timer **432**) to capture measurement data and to transmit the measurement data to the gateway **104**. In some embodiments, the controller **402** may wake up to capture radiant temperature parameters every 30 minutes, ambient temperature every five minutes, self-temperature measurements every 30 minutes, humidity every 30 minutes, PIR every 500 mS, and user input on demand.

In operation, the controller **402** may remain in a lowest available sleep mode (idle or low power mode) during the inactive interval. In certain embodiments, only the timer **432** (such as a real-time clock (RTC)) and a PIR circuit, which may be part of the sensor controller, may remain active during the idle period. To conserve power, other circuit elements and peripherals of the circuit **400** may enter a low power state or be turned off during idle periods. Upon wake up, the controller **402** may activate the relevant sensor and capture the measurement.

In certain embodiments, the humidity sensor **420** may be powered using a general purpose input/output (I/O) of the controller **402**. When the interval for humidity measurements expires, the controller **402** may turn the humidity sensor "ON" and then commence with the measurement. Once the measurement is complete, the controller **402** may turn off the sensor and then return to an idle state. By turning on and off components as needed, the circuit **400** may operate using solar energy and stored power, reducing the overall average power consumption.

In some embodiments, the controller **402** may be implemented using an MCU that has multiple low power modes, each of which provide a different level of current consumption. There may be some cases where the MCU may be placed in one low power mode while a particular sensor is measuring the parameter and may return to another low-power state thereafter.

In some embodiments, the circuit **400** may enter an initial state when the system is powered on for the first time. In order to start the installation process, a touch sequence may be activated on the touch screen **310** to enter the installation mode. The touch screen may include a GUI that may show several parameters, such as an illuminance and luminous emittance value (Lux value) from the solar cells and light sensors as well as radiant temperature. In some embodiments, the control element **102** may be placed opposite a largest wall surface that has the largest thermal mass for the radiant sensor measurement. After the particular area within the zone has been determined (i.e. a specific hallway or room), the elements identified will be the key elements that will be used to determine the placement of the sensor within the zone. At this time, the controller **402** and any integrated peripherals may be configured for their default operation. For example, the controller **402** may initialize system clocks; may configure general purpose I/Os for the correct default state after power up (display, power controls, energy harvester, etc.); may configure a serial peripheral interfaces (SPIs) for the wireless transceiver and for the touch screen controller; may configure Inter-integrated circuits (I^2Cs) for the humidity sensor, for the ambient light sensor, and for the radiant temperature sensor; may configure an analog-to-digital converter (ADC) for the passive infrared (PIR) sensor; and may measure voltages of the back-up battery and solar cell.

In some embodiments, the distributed control elements **402** may be placed in selected locations to maximize the solar energy that strikes the surface of the solar cells. In addition, placement of the sensor node should maintain accurate sensor measurements of the ambient conditions such as light, temperature and humidity as well as the performance of the radiant temperature measurements and the PIR occupancy sensor. In order to determine the optimal placement of the sensor, the controller **402** may run a built-in

test during the installation process, which built-in test may attempt to measure and optimize all of the parameters while maintaining sufficient energy to charge the system. In certain embodiments, accurate sensor measurements may be the paramount concern, in which case total solar energy to the cells may be sacrificed in favor of accurate sensor measurements.

In some embodiments, the distributed control element **102** (including circuit **400**) may be positioned to obtain the best possible values for all parameters while maintaining the connection to the gateway **104**. In some embodiments, the placement of the control element **102** may achieve a wall temperature (radiant temperature) measurement that provides an accurate representation of the thermal properties of the wall being measured. A signal strength measurement (by the wireless transceiver **430**) may provide an indication of the proximity of the circuit **400** to the gateway **104**. An ambient light measurement may be used to maximize the amount of light striking the surface of the solar cell, which may be a direct correlation to the amount of charge time. Once the location of the sensor has been determined, then the RF power of the circuit **400** can be set. After selecting "OK," the circuit **400** may start an algorithm that sends a signal including a received signal strength indicator (RSSI) to the gateway **104** and the gateway **104** may verify the RSSI value on its end. A new value of the RF output power of the circuit **400** can be determined to reduce the overall current consumption by the circuit **400** in order to reduce the load. The new value may be sent to the circuit **400** to program the RF transceiver registers and the algorithm may be tried again to confirm the settings. Once a suitable combination of packet error rate (PER) along with minimum signal strength has been determined, the system may transition to normal operating mode and will be ready to use.

During operation, the circuit **400** may be responsible for the overall measurement of the sensors including: radiant temperature, ambient temperature, humidity, passive infrared and ambient light. The sensor will remain in the lowest power sleep state while not performing any measurements. After either the default time-out period or the time-out period defined by the gateway, the node will take the defined measurement for that period. Each sensor may have its own defined interval and may not be measured at each wake event. In some embodiments, the wake interval used for the humidity and temperature measurements may be configured dynamically. For example, the circuit **400** may have a default timing interval for wakeup and measurement it is deployed, but the HVAC management system **112** may send a signal to the gateway **104**, which may communicate a timing adjustment to the circuit **400** to adjust the wake interval of the circuit **400**, enabling lower power operation of the sensors (in some instances) by decreasing the average current consumed by the circuit **400** by increasing the time interval between transmissions. The interval will be a variable parameter that can be updated in the firmware through a command issued from the HVAC management system **112** through the gateway **104** and to the circuit **400**.

FIGS. **5**A-**5**C are timing diagrams of a startup sequence, a calibration routine, and a pulse signature detection routine, according to certain embodiments. FIG. **5**A depicts a graph **500** of a first portion of the startup sequence, which may be configured to last for a period of time, such as thirty seconds. During that first portion, wakeup functions relating to the passive infrared (PIR) are performed. Additionally, the controller **402** may test to ensure that a certain glitch width is seen before setting the occupant detection threshold. The digital signal processing deglitch time may be related to a period of time when an analog-to-digital converter (ADC) threshold of the controller **402** has been crossed and compared to a predefined time-out period of 32 ms. A signal width less than 32 ms period may be deglitched as a zero, while a signal width of greater than 48 ms may be deglitched as a 1. The routine depicted in graph **510** implements a single pulse mode that readies the circuit **400** to recognize different pulse signatures and that will trigger the algorithm output signal to produce a pulse of a pre-determined duration in response to toggling of either the positive comparison or the negative comparison signal.

FIG. **5**B depicts a graph **520** of the first portion of the startup sequence, which may be configured to last for the period of time. In graph **520**, a pulse recognition it is noted that the time period between the rising edge of the positive comparison signal pulse and a rising edge of the negative comparison input pulse is approximately five seconds. In a dual pulse mode, the circuit **400** looks for two pulses from opposite comparison to occur within a timeout window of five second. If the adjacent pulses fall outside of the time window (i.e., greater than five second), the algorithm output signal will not produce a pulse, and the pulse recognition routine will be restarted.

In FIG. **5**C, the graph **530** depicts the two pulses from opposite comparison (i.e., positive comparison and negative comparison) within the five second window. In this instance, the negative comparison pulse is detected within the time window, and the algorithm output signal produces a pulse of a pre-determined duration in response to detecting both pulses within the time window.

FIG. **6** is a block diagram of an environmental control system **600** including a gateway **104** configured to communicate with distributed control elements **102** (wirelessly) according to certain embodiments. The gateway **104** may communicate with HVAC management system **112** through the network **110**. The gateway **104** may also communicate with the HVAC system **108** of a particular structure through the HVAC controller **106**.

The gateway **104** may include a wireless interface **604** configured to communicate wirelessly with the control elements **102**. The gateway **104** may further include a processor **606** coupled to the wireless interface **604** and to a network interface **608**, which may be communicatively coupled to the network **110**. The processor **606** may be coupled to a memory **610**, a database **612**, and an input/output (I/O) interface **614**. The I/O interface **614** may be coupled to the HVAC controller **106** through a wired or wireless communication link. In some embodiments, the database **612** may be stored in the memory **610**.

The memory **610** may include HVAC controller instructions **616** that, when executed by the processor **606**, cause the processor **606** to communicate control signals to the HVAC controller **106**. The memory **610** may also include control elements controller instructions **618** that, when executed, cause the processor **606** to communicate control signals to the distributed control elements **102**. Further, the memory **610** may include communications controller instructions **620** that, when executed, cause the processor **606** to send data or commands to or receive data from the distributed control elements, the HVAC management system **112**, or the HVAC controller **106**.

In certain embodiments, the gateway **104** receives data from one or more of a plurality of the control elements **102**. The data may include measurement data of one or more environmental parameters, user input data, or any combination thereof. The gateway **104** may receive the data in response to a request sent from the gateway **104** to one or

more of the control elements **102**. In certain embodiments, the gateway **104** may receive the data periodically or in response to a user input received at one of the control elements **102**.

The gateway **104** may send at least a portion of the data to the HVAC management system **112**, may receive a control signal from the HVAC management system **112** in response to sending the portion, and may provide a signal to the HVAC controller **106** in response to the control signal. The signal provided to the HVAC controller **106** may include a command or control instruction to control operation of the HVAC system **108**.

In some embodiments, the gateway **104** may be unable to communicate with the HVAC management system **112**. In this example, the gateway **104** may execute the HVAC controller instructions **616** to control operation of the HVAC system **108** in response to the data from the control elements **102**.

In some embodiments, it may be desirable to update firmware associated with one or more of the control elements **102**. Since there are no wired connections between the gateway **104** and the control elements **102**, the gateway **104** may provide Over-the-Air Programming (OTAP). Each control element **102** may be capable of updating its firmware, restarting and then reconnecting (communicatively) to the gateway **104**. In some embodiments, prior to updating the firmware, the gateway **104** may request and store a snapshot of all the operating parameters of the control element **102** by sending a signal to the control elements **102** and receiving the snapshot in response thereto. The gateway **104** may store the snapshot prior to erasing the flash and may then restore all of the parameters after the firmware has been modified.

FIG. **7** is a block diagram of a gateway **700** for use with an environmental control system according to certain embodiments. The gateway **700** may be an embodiment of the gateway **104** in FIGS. **1-4** and **6** above. The gateway **104** may operate as a bridge between the wireless control elements **102** and the HVAC controller **106**. Further, the gateway **104** may control the automation systems deployed within the home or structure. In addition, various interfaces may be provided as a means for expansion of the capabilities. For example, the Zigbee Smart Energy (SE) interface may be included to allow communication with utility systems for power monitoring.

The gateway **700** may include a microprocessor core including cache memory. The gateway **700** may include a serial peripheral interface (SPI) which may couple the core to one or more ZigBee® enabled devices, such as lights, washing machines, microwaves, televisions, and various appliances and devices via a ZigBee® module. The gateway **700** may further include a Universal Serial Bus (USB) interface configured to couple to a USB hub, USB physical layers, and optional ZigBee® USB dongle, which may permit communication between the gateway **700** and a utility meter.

The gateway **700** may include a local bus, which may be coupled to a memory device, such as a flash memory. The gateway **700** may also include a double data rate synchronous dynamic random-access memory (DDR2) interface configured to couple to a DDR2 device. The gateway **700** may include an Inter-Integrated circuit (I2C) bus coupled to an I2C real-time clock (RTC), a temperature sensor, and an MCU, which may be coupled to a power sequencing/monitoring circuit. The gateway **700** may further includes a secure digital high capacity (SDHC) interface coupled to the electrically erasable programmable read only memory (EEPROM) or to a standard capacity card slot. The gateway **700** may also include a Peripheral Component Interconnect Express (PCIe) interface and a serializer/deserializer (SerDes×1) which may communicate via a short-range wireless communication with an external device, such as a smart phone. The gateway may further include network interfaces (eTESC1 and eTESC2) which may communicate with a router through a network connection. The gateway **700** may further include a dual universal asynchronous receiver/transmitter (DUART) which may communicate with a DB9 or RS 232 connector.

In certain embodiments, the gateway **700** may include a core processor that may execute an operating system, such as Linux, and the various operations may be controlled based on one or more Linux applications. The gateway **700** may receive data from one or more sensor nodes, such as control elements **102** or other sensor nodes, and may send the data to the HVAC management system **112**. In addition, the gateway **700** may receive processed data, instructions, or any combination thereof from the HVAC management system **112** and may communicate with actuators, controllers or other nodes to turn on or off lighting, and to control HVAC and other home automation systems.

In certain embodiments, upon power up, the gateway **700** may register with the HVAC management system **112**. The gateway **104** may pull data from the UART connected wireless access point (via CDC class, which is already part of the kernel build). The gateway **700** may concatenate any data from the multiple control elements **102** or other sensor nodes, if required. In some embodiments, the data may be stored until sent off to the server. The gateway **700** may capture snapshot data from the third party home controller (current state of all connected devices for lighting, HVAC, shades etc.). The gateway **700** may format the data to be sent to the HVAC management system **112** and send it through the interface if connected to the ISP (WAN if operating as the home router or WiFi if connected to another router). The gateway **700** may concatenate snapshot data with the current measured values. The gateway **700** may also store the data as a text file. In some embodiments, the gateway **700** may receive data from the server and pass it to a third party controller (LAN port) or to one or more actuators. In certain embodiments, the gateway **700** may implement manual thermostat functions based on the measured values from the control elements **102**. The gateway **700** may send an alert to the HVAC management system **112**, to a user device, or both, if the gateway **700** detects an issue with one of the control elements **102**. The gateway **700** may pull data from the Zigbee® module and pass the data to the HVAC management system **112**. The gateway **700** may provide software update method from the HVAC management system **112** to be able to update the gateway **104** and to provide firmware update capability to the controller elements **102**. In some embodiments, the gateway **700** may provide a web application interface through which a customer may connect to the gateway **700** to see system operation and configuration information.

FIG. **8** is a block diagram of a packet format **800** for data transmission between sensor nodes and a gateway of an environmental control system according to certain embodiments. The packet **800** may include a header **802**, a control byte field **804** (which may include 1 byte of data), a payload field **806** (which may include 1-10 bytes of sensor data), and a frame check sequence (FCS) **808**. The control byte field **804** may include a PIR status bit **810**, two reserved bits **812**, and five bits indicating the packet type.

In certain embodiments, the control element **102** may assemble data from multiple sensors and assemble the data

into a suitable packet for wireless transmission to the gateway **104**. The wireless protocol handles all of the low level functions that enable each of the control elements **102** (or nodes) to join the network provided by the gateway **104** and to pass the data to the gateway **104** through the network. Each packet may include a control byte that identifies they type of data contained within the packet and the data payload. The data in the payload may include at least the high byte and low byte of each measured value according the ordering of the packet data outlined. The packet formats are discussed below with respect to FIGS. **9**A-**9**D and FIGS. **10**A-**10**C.

FIGS. **9**A-**9**D are packet formats for ambient temperature, radiant temperature, ambient light, and power levels respectively, according to certain embodiments. The packet formats may be packets sent by control elements **102** to the gateway **104** (or **700** in FIG. **7**). In FIG. **9**A, the ambient temperature packet (generally indicated at **900**) includes a header field **902**, a control byte **904** (0x01), an ambient temperature payload **906** including a high byte and a low byte, and the FCS **908**.

In FIG. **9**B, the radiant temperature packet is shown and generally indicated at **910**. The packet **910** includes a header **912**, a control byte **914** (0x02), a radiant temperature field **916** (2 bytes), a humidity field **918** (2 bytes), and the FCS **920**.

In FIG. **9**C, the ambient light packet is shown and generally indicated at **930**. The packet **930** includes a header **932**, a control byte **934** (0x03), a visible light field **936** (2 bytes), a red light field **938** (2 Bytes), a green light field **940** (2 bytes), a blue light field **942** (2 bytes), an infrared light field **944** (2 bytes), and an FCS **946**.

In FIG. **9**D, the system power level packet is shown and generally indicated at **950**. The packet **950** includes a header **952**, a control byte **954** (0x04), an energy harvesting (EH) voltage level 956 (2 bytes), a back-up battery voltage **958** (2 bytes), and an FCS **960**.

FIGS. **10**A-**10**C are packet formats for comfort zone settings, acknowledgment, and negative acknowledgment respectively, according to certain embodiments. The packet formats may be packets sent by control elements **102** to the gateway **104** (or **700** in FIG. **7**). In FIG. **10**A, a comfort zone setting request packet is generally indicated at **1000**. The comfort zone setting request packet **1000** includes a header **1002**, a control byte **1004** (0x05), a comfort zone setting request payload **1006**, and an FCS **1008**. The comfort zone setting request payload **1006** may include user input received via the touch screen of the control element **102**.

In FIG. **10**B, an acknowledgment packet is generally indicated at **1010**. The acknowledgment packet **1010** may include a header **1012**, a control byte **1014** (0x06), an acknowledgement payload **1016** (1 byte), and an FCS **1018**. The acknowledgment packet **1010** may be sent by the gateway **104** or the control element **102** in response to successful receipt of a signal.

In FIG. **10**C, a negative acknowledgment packet is generally indicated at **1020**. The negative acknowledgment packet **1020** may include a header **1022**, a control byte **1024** (0x07), a negative acknowledgment payload (NACK) **1026** (1 byte), and an FCS **1028**. The negative acknowledgment packet may be sent by the gateway **104** or the control element **102** in response to unsuccessful receipt of a signal.

The present disclosure provides an adaptive, Web-assisted energy management technology that works harmoniously with geo-specific natural environments and human interactions. Adaptive algorithms of the system increase a building's thermodynamic efficiency by simplifying and optimizing the occupant-equipment-environment interactions

How Does the Intelligent Energy System Work? The system is designed to solve issues that current technologies on the market fail to address. In certain embodiments, the sensors may be peel-and-stick devices for simple installation and operation. To make them even more effective, they harvest energy from ambient light to eliminate the need for batteries (FIGS. **1**-**3**). The control element may include a linguistic human interface that incorporates text and a touch-screen interface to facilitate user interactions.

The simple touch screen allows the user to answer the question "are you comfortable?" Users touch the screen to indicate whether the room is too hot, too cold, too bright or too dark, or comfortable; that's it. No other interaction is required. The system continuously monitors parameters such as temperature, humidity, radiant environment temperature, ambient light level, light color (thus source), and occupancy; and transmits the result through a wireless communications link to the gateway **104**, which may communicate at least some of the data to the HVAC management system **112**, which may include an intelligent energy engine. The gateway **104** provides wireless connectivity to the control elements **102** as well as plug-and-play and interoperable with numerous systems, including ZigBee® and other protocols. The HVAC management system **112** may be a standalone server and may include an adaptive artificial intelligence (AI) engine. In some embodiments, the adaptive AI engine may be cloud-based and always improving to keep the maintenance and upkeep at the point-of-use low. The HVAC management system may continuously learn and improve the comfort and energy efficiency parameters fed back from users. The HVAC management system **112** may compare individual building data with reference systems developed over time from similar micro- and macro-climate environments, and may provide output to the building subsystems such as HVAC, lighting, windows, zone damper vents, etc. Since the entire system may be wirelessly connected, even the firmware of the sensors (control elements **102**) may be updated if new, more effective user interfaces are developed, allowing for seamless improvements and upgrades.

To affect the net consumption of energy without sacrificing building comfort, the HVAC control may address design considerations, equipment strengths and weaknesses, and enhance controls. Better designed buildings and better retrofitting may cause buildings to be or become inherently (passively) more efficient. For example, better insulation, less infiltration, more thermal mass, and other parameters may result in more efficient structures.

Incorporation of better equipment may cause the overall energy consumption to decrease. In particular, utilization of more efficient energy conversion subsystems, such as Ground and Air Source Heat Pumps and Hybrid Domestic Hot Water systems, LED Lighting, energy recovery systems, etc., may reduce overall energy consumption. Further, smart thermal and energy management of buildings may be introduced to manage load profiles and increase the thermodynamic efficiency of building energy conversion subsystems such as the HVAC.

FIG. **11** depicts a set of human comfort factors **1100** that are highly subjective, dynamic and multivariable. The human comfort factors **1100** may include age, gender, personality, light intensity and color, metabolic rate, season, ambient light, air quality, time (of day), geographic location,

environment, air temperature, mean radiant temperature, humidity, sound, occupancy, and clothing (clothing being worn).

FIG. **12** is a block diagram of an environmental management system **1200** according to certain embodiments. The environmental management system **1200** (or HVAC management system) may include a multivariable adaptive control that uses numerous comfort factors affecting the entire system.

The environmental management system **1200** includes the HVAC management system **112** communicatively coupled to the gateway **104**, and optionally to the AC unit **1202**. In certain embodiments, signals from the HVAC management system **112** are communicated to the air-conditioning (AC) unit **1202** through the gateway **104** (as indicated by the dashed arrows in FIG. **12**). The AC unit **1202** may be coupled to the plant **1204** (i.e., the structure having an environment to be controlled). The plant **120** provides feedback via the distributed control element(s) **102**, which transmit sensor data, user input, or any combination thereof to the gateway **104**. The gateway **104** communicates the data to the HVAC management system **112**.

The HVAC management system **112** may include a Monte Carlo analyzer **1210** and a spatial-temporal data miner **1208**, which may process the data to provide respective outputs to a node **1212**, which may be coupled to a neural network **1214**. The neural network **1214** may include an output coupled to a node **1216**, which includes a second input to receive ASHRAE composite psychometric human comfort parameters and which includes an output. The output of the node **1216** may be coupled to inputs of a MN adapt module **1226**, which provides an output to a node **1228**. The node **1228** includes a second input to receive an output from the spatial-temporal data miner **1208** and includes an output coupled to an inference engine **1224**.

The inference engine **1224** includes a first output that is coupled to a fuzzify module **1218**, a second output coupled to a control rules module **1220**, and a third output coupled to a defuzzify module **1222**. The fuzzify module includes an input coupled to the node **1216** and an output coupled to the control rules module **1220**. The control rules module **1220** includes an output coupled to the defuzzify module **1222**, which has an output coupled to a node **1206**. The node **1206** may have an input coupled to the gateway **104**, an input coupled to a control element **102**, and an output to provide an error signal ϵ to the AC unit **1202**. The AC unit **1202** also receives the environmental load and provides an output (u), which is applied to the plant **1204**. The resulting output is then fed back through the control element **102** to the gateway **104** and optionally to the node **1206**.

In certain embodiments, in addition to periodically measuring temperature and humidity, the gateway **104** via the control elements **102** may continuously monitor other critical parameters, such as radiant background, mean radiant temperature, ambient light level and color (thus source) and occupancy at regular intervals. The gateway **104** may transmit the resulting data through the gateway **104** to the HVAC management system **112**, which may use an AI to process the data and to provide control signals to improve the efficiency of the system. The data miner **1208** may mine the data based on user interactions and specific user demands.

FIG. **13** is a block diagram of an environmental management system **1300** according to certain embodiments. The environmental management system **1300** includes an HVAC management system **112** coupled to multiple gateways **104** through a wide area network (WAN) **110**, such as the Internet. The HVAC management system **112** may receive data from multiple gateways **104** and may individually track comfort settings associated with each of the gateways.

In certain embodiments, the HVAC management system **112** may include a network interface **1302** coupled to the network **110**, a processor **102** coupled to the network interface **1302**, a database **1306**, and a memory **1308**. In some embodiments, the database **1306** may be part of the memory **1308**.

The memory **1308** may store instructions that, when executed, cause the processor to process sensor data using a spatial-temporal data miner **310**, process the sensor data using a Monte Carlo analyzer **1312** and process the outputs using a neural network **1314**. The memory **1308** may further store instructions that, when executed, may cause the processor to draw inferences from the processed data using an inference engine **1316**. The memory **1308** may also include control rules that, when executed, cause the processor **1304** to generate control signals for transmission to the gateway **104** based on fuzzified data from fuzzify/defuzzify instructions **1320**. The memory **1308** may also include communication protocols that, when executed, cause the processor **1304** to organize the control signals, data, instructions, or any combination thereof for transmission to the gateway. The memory **1308** may further include adaptation algorithms **1324** that, when executed, cause the processor **1304** to adjust one or more control instructions, to learn from accumulated data, or any combination thereof. The memory **1308** may also store weather/geography information **1326** that may be used by the processor **1304** to process the data according to the geographic location of the structure.

In certain embodiments, the environmental management system **1300** may be an intelligent energy system that may take into account home data including occupant patterns, outside information, temperature, humidity, light, occupancy, etc. The environmental management system **1300** may also take into account micro environment information, such as neighborhood patterns and smart grid information. Further, the environmental management system **1300** may incorporate weather information, such as weather forecasts and energy management trends, and may produce control signals to control lights, HVAC systems, renewable energy systems and so on.

FIG. **14** is a block diagram of an environmental management system **1400** that provides multivariable adaptive control based on numerous comfort factors and external factors affecting the system. As discussed above with respect to FIG. **13**, the environmental management system **1400** may incorporate external information, such as weather data, historical information (local and national), energy management trends, and neighborhood information, to enhance the user's experience. The system can learn from others what works best and can adapt the user's controls to provide an enhanced experience.

FIG. **15** is a diagram of a multi-variable thermal analysis model **1500** of a plant (such as a residence) according to certain embodiments. The model **1500** may include north and south wall-window models, including radiant and convection flow models ($R_{rad\text{-}N}$ and $R_{conv\text{-}N}$). The model **1500** may further include a ceiling model including thermal flow. The model **1500** further includes forced air and radiant floors and includes a Trombe wall, which acts to reduce thermal flow.

The model **1500** includes a control element, which senses various parameters and communicates data to a first input of a comparator, which includes a second input responsive to signals from the HVAC management system **112** and which

includes an output coupled to the forced air unit and to the radiant floors to adjust various parameters.

The model **1500** recognizes that there are multiple factors that impact human comfort, which factors may be impacted by the surrounding environment as well as by the structure itself. Further, the model **1500** recognizes that certain features may impact the human comfort experience, which may be adjusted via the control loop provided by the control element **102** and the HVAC management system **112** in conjunction with the HVAC and radiant systems of the plant.

FIG. **16** depicts a graph **1600** of relative humidity versus mean radiant temperature in a psychometric chart that correlates such parameters to perceived comfort according to certain embodiments. The graph **1600** indicates a correlation between humidity, temperature and perceived comfort level. The HVAC management system **112** may take advantage of this correlation in providing parameter adjustments to the gateway **104**, such that the HVAC system may be adjusted to enhance comfort as opposed to merely raising or lowering the temperature.

FIG. **17** depicts a set of entropy equations according to certain embodiments. In Equation 1, the work performed by the system is written as the change in energy of the system. Equation 1 can be rewritten as shown in Equation 2 or, an increase in the internal energy of a system is its absolute temperature times net entropy change (or heat) minus pressure times the volume (or work). For example, a heat engine, such as that of an automobile, transfers heat from a hot source (combustion of fuel) to a heat sink (ambient air), thus producing work (moving the car). The maximum work efficiency of this cycle is determined by the Carnot efficiency given in Equation (3), which notes that maximum power output is gained when the temperature difference between the hot source and cold sink is at a maximum. Conversely, the reverse of a heat engine is a heat pump. Because heat always flows from a hot source to a cold sink, work is required to lift this heat from the cooler sink to a warmer source. This is the fundamental process by which refrigeration and air conditioning is performed and is denoted in Equation (4).

It is also evident from above equation that minimum work (maximum system efficiency) is achieved when the temperature differential between the heat sink and the hot source is at a minimum. This is why heat pumps provide maximum coefficient of performance in moderate climates (i.e., heat lift is minimized). Entropy is system waste that cannot perform useful work, and it is defined by Equation (5), which indicates that change in entropy equals heat transferred divided by the absolute temperature in K. This equation indicates that transferring heat at a higher temperature and minimizing the thermal difference at which heat is transferred also minimizes entropy gain. This is the fundamental reason that a technique other than threshold based ambient temperature is needed to maximize the efficiency of a home or a building. To be specific what we need to control our building HVAC systems for peak performance depends on far more variables than a set point ambient temperature which trips the unit regardless of other variables.

Referring now to FIG. **18**, for example, a south-facing wall exposed to the winter sun is a good source of radiant heat and source of comfort even if the ambient air temperature of the room has been kept to a few degrees lower than would otherwise be selected as comfortable, before the occupants get home. To know when to turn the equipment on and off and to understand what exact temperature to set the thermostat, the HVAC management system **112** may analyze a number of variables (determined over time) and may determine a solution that is unique to the occupant, to the building, to the time of day and the weather, etc.

FIG. **19** is a diagram of a neural network-based intelligent energy engine **1900** according to certain embodiments. The engine **1900** takes into account state space variables to provide a dynamic feedback control system through when the user's comfort level may be effectively managed. In an example, sensor data is applied to determine the comfort error, which is then fed to a function to adjust the various building systems iteratively until the desired comfort level is achieved. Over time, the system may develop intelligent defaults in order to quickly and appropriately adjust the user's environment as desired.

FIG. **20** is a block diagram of an environmental management system **2000** according to certain embodiments. In the illustrated example, the environmental management system **2000** may utilize touch sensors, which may communicate with servers through a gateway, which is configured to communicate with one or more systems of a building. The servers, the gateway and the touch sensors may be commercially available through Altumaxis, Inc. of Austin, Tex.

FIG. **21** is a block diagram of an adaptive feedback intelligent energy engine **2100** according to certain embodiments. The illustrated example is similar to that described above with respect to FIG. **12**, except that the neural network and adaptation features are incorporated into a single block, and the control rules are out of the data path between the fuzzify and defuzzify blocks and are replaced with the inference engine.

FIG. **22** is a perspective view of a residence that may utilize the systems and methods described above with respect to FIGS. **1-22**.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the scope of the invention.

What is claimed is:

1. An apparatus comprising:

a plurality of sensors including a radiant temperature sensor, an ambient air temperature sensor, and a humidity sensor;

a transmitter coupled to the plurality of sensors and configured send data to a gateway through a wireless communication link, the gateway configured to couple to a network and to communicate data to a gateway management system through the network;

a solar cell configured to provide power to the plurality of sensors and the transmitter; and

an adhesive backing configured to secure the apparatus to a structure.

2. The apparatus of claim **1**, further comprising a touchscreen interface to:

provide a graphical user interface; and

receive input corresponding to the graphical user interface.

3. The apparatus of claim **1**, wherein the plurality of sensors further includes a light sensor.

4. The apparatus of claim **3**, wherein the light sensor comprises at least one of an infrared sensor, a red green blue (RGB) sensor, and an ambient light sensor.

5. The apparatus of claim **1**, wherein the plurality of sensors comprises a motion sensor.

6. The apparatus of claim **1**, further comprising:

a timer; and

wherein the plurality of sensors and the transmitter operate periodically in response to a signal from the timer.

7. An environmental control system comprising:
a plurality of control elements, at least some of the control elements including:
a plurality of sensors including an ambient air temperature sensor and a radiant temperature sensor;
a transceiver coupled to the plurality of sensors and configured send data to a wireless communications link; and
a solar cell configured to provide power to the plurality of sensors and the transmitter; and
a gateway configured to receive data from the transceiver and to selectively control a heating, ventilation and air-conditioning (HVAC) system according to the data.

8. The environmental control system of claim 7, wherein each control element includes an adhesive backing configurable to secure the control element to a structure.

9. The environmental control system of claim 7, wherein each control element further comprises a touch-screen interface to:
provide a graphical user interface; and
receive input corresponding to the graphical user interface.

10. The environmental control system of claim 7, wherein the the plurality of sensors further includes:
a humidity sensor; and
a light sensor.

11. The environmental control system of claim 10, wherein the light sensor comprises at least one of an infrared sensor and a red green blue (RGB) sensor.

12. The environmental control system of claim 7, wherein the at least one sensor comprises a motion sensor.

13. The environmental control system of claim 7, wherein each control element further comprises:
a timer; and
wherein the at least one sensor and the transmitter operate periodically in response to a signal from the timer.

14. An apparatus comprising:
a touch screen;
a plurality of sensors including an ambient air temperature sensor, a radiant temperature sensor, and a light sensor configured to capture sensor data;
a transmitter coupled to the touch screen and configured send data from the touch screen and the sensor data to a gateway through a wireless communication link; and
a solar cell configured to provide power to the touch screen, the plurality of sensors, and the transmitter.

15. The apparatus of claim 14, further comprising an adhesive backing configured to secure the apparatus to a structure.

16. The apparatus of claim 14, wherein the touch screen is configured to:
provide a graphical user interface; and
receive input corresponding to the graphical user interface.

17. The apparatus of claim 14, wherein the plurality of sensors further includes a humidity sensor.

18. The apparatus of claim 17, wherein the sensor data sent by the transmitter includes at least one of ambient temperature data, radiant temperature data, humidity data, and light data.

19. The apparatus of claim 14, wherein the plurality of sensors further includes an infrared sensor.

20. The environmental control system of claim 10, wherein the light sensor comprises an ambient light sensor.

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